IVHS and Rural Road Safety: A Prototype ATIS

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EXECUTIVE SUMMARY

A research study was conducted to investigate the potential application of Intelligent Vehicle/Highway Systems (IVHS) technologies for reducing accidents on rural roads. After studying existing technologies, their present application to transportation, and approaches to identifying predominant accident characteristics, a prototype Advanced Traveler Information System (ATIS) for a rural region was developed.

A significant proportion of all accidents that occur in rural areas are winter related accidents. The situation is aggravated in states, like Utah, that attract many out of state tourists for winter recreational activities. An ATIS is proposed that (1) serves a large region, as opposed to a single corridor, (2) provides pre-trip travel information, as opposed to en route information, and (3) provides current information on road condition.

A cost-benefit analysis of the proposed ATIS has been conducted. Two technologies, namely satellite and radio, are explored for providing location information for maintenance vehicles. These vehicles can be tracked by a roadway management center. Location data are used to create a temporal map indicating when roads were last serviced (plowed, salted, etc.). Additional information on accidents, avalanches, road closures, etc. are added to this database at a central Roadway Management Center (RMC). Current roadway information is then transmitted to remote sites, in malls, hotel lobbies, resorts, major office buildings, etc. for travelers to consult prior to taking a journey. Television may also be used as a medium of communication for current roadway data. Hardware, software, and labor costs are used to estimate cost of the ATIS.

Benefits of the system are savings resulting from reduced accidents. Unfortunately, traveler's use of these systems has not been studied sufficiently. It is difficult to predict how many people will benefit from the information by either delaying a

trip, selecting a safer route, or driving more cautiously. Consequently, the benefit analysis conducted here involved, (1) analyzing historical data on winter weather accidents that were stratified by severity, (2) predicting the number of winter weather accidents by severity that would occur during a ten year period if the ATIS were not implemented, and (3) determining the amount of savings that would be incurred if the system were effective in decreasing the number of winter weather accidents by a certain percent. An additional benefit, that has not been quantified in this report, is collection of an accurate and comprehensive database on maintenance activities for use in planning and budgeting future needs.

The cost -benefit analysis indicated that the net present value of the ATIS is positive with an overall 2 percent reduction in winter weather accidents. Furthermore, with a 2percent reduction in accidents, the system pays for itself in nine years. This number decreases significantly with a 3 percent accident reduction. Sensitivity analysis was performed to determine the stability of the model.

Finally, another component of the research effort was to develop a simulation model to track maintenance vehicles such that cost is minimized. Generally, location finding technologies are not very accurate in mountainous terrain and under adverse weather conditions. Further, most technologies have a fee associated with their use, based on the number of times a location is requested. A third factor in development of the simulation model is that maintenance vehicle's routes are dynamic. Vehicles respond to current needs and are sometimes used to assist with county and local operations. Finally, commercially available vehicle location/navigation packages are not designed to identify paths over which a vehicle has traveled. The question they address is, "What is the current location of the vehicle?." The ATIS application described here requires that each vehicle's path be identified in order to communicate temporal information on when a maintenance vehicle last plowed/salted a road. The simulation model developed in this study has been tested in a laboratory environment. Further testing is required in a real environment by mounting GPS devices in vehicles and using the model to track vehicles in the mountains during adverse weather.

CHAPTER 1

Introduction

In the last few years, a great deal of consideration has been given to making innovative technological changes in the field of transportation to relieve worsening congestion and improve safety. The United States is moving from the Interstate Highway program of the 1960s to the advanced technology-based transportation program of the 21st century. Research on advanced technology applications in transportation has been conducted for several years. Under the name, "Intelligent Vehicle/Highway Systems" (IVHS), this program hopes to make significant improvements in mobility, highway safety, and productivity by building transportation systems using advanced electronic technologies and control software. IVHS involve integrated application of advanced surveillance, communication, computer, display, and control process technologies both in the vehicle and on the highway.

The IVHS program has been divided into five categories: (1) Advanced Traffic Management Systems (ATMS), (2) Advanced Traveler Information Systems (ATIS), (3) Advanced Vehicle Control Systems (AVCS), (4) Commercial Vehicle Operations (CVO), and (5) Advanced Public Transportation Systems (APTS).

ATMS are used to monitor real-time traffic flow and predict congestion. These systems include area-wide surveillance and detection systems, management of such functions as traffic signal operation, ramp metering, and other operational strategies to reduce congestion and mitigate incidents. Transportation data used for these applications include collected origin-destination information and detected traffic volumes.

ATIS provide drivers with information on congestion, alternate routes, navigation, location, and roadway conditions, with the use of audio and visual devices in the vehicle and at the roadside (e.g. variable message signs). These systems also provide pre-trip information via radio, television, and telephone to assist in trip planning at home and work. Information relayed to drivers includes local accidents and delays at work zones, location of fog or ice on the roadway, alternate routes, recommended speeds, lane restrictions, etc. The anticipated benefits of these systems depend on the complex interactions among different traffic system components.

At present ATMS and ATIS are being applied in the "Smart Corridor" program in Los Angeles. Another example of an ATIS application is AUTOGIDE, developed for London by the British, in which the static route guidance benefits were estimated at $500 to $600 per vehicle per year (Jeffrey, 1987). For the metropolitan Seattle area this would correspond to a system-wide annual benefit of approximately $60 million (NCHRP, 1991). Another application of ATMS/ATIS is TravTek, a project to demonstrate motorist information systems and in-vehicle route guidance in Orlando, Florida.

AVCS provide information about changing conditions in a vehicle's immediate environment. Devices in the vehicle sound warnings and assume partial or total control of the vehicle. This technology includes such hazard warning systems as forward object detection, blind spot and red light warning devices, lane-keeping devices, adaptive cruise control, etc. The technology can be used to relieve drivers of most driving tasks in high-demand traffic corridors or on long-distance, high-speed trips. AVCS technology will require long-term research before it can be applied reliably.

CVO systems are used to improve toll collection, efficiency of commercial operations, and fleet management such as hazardous materials tracking, cargo identification units, etc. The HELP (Heavy-vehicle Electronic License Plate) program along the Pacific Coast and into Arizona and Texas represents a regional application of

CVO. Components of the HELP program focus on five technologies that can be integrated into a comprehensive management system (Walton, 1991), namely:

- Automatic Vehicle Identification (AVI),
- Weigh-in-motion (WIM),
- Automatic Vehicle Classification (AVC),
- Satellite data links, and
- Data communication network including on-board computers.

APTS is a new category added recently to IVHS. It has four major objectives:

- To increase ride sharing and transit ridership,
- To improve safety and security in a transit system,
- To reduce operating costs and increase revenues for transit systems,
- To assist various transit agencies respond to legislative mandates, such as the Clean Air Act Amendments of 1991, etc.

Research activity on IVHS has been increased significantly with the passage of the Intermodal Surface Transportation Efficiency Act (ISTEA) in 1992. In July, 1991, the Mountain Plains Consortium (MPC) of the University Transportation Centers, Region VIII, funded Utah State University to explore the application of Intelligent Vehicle/Highway Systems (IVHS) in rural areas. The primary objective of the research was to examine IVHS technology that could potentially improve safety on rural roads.

The research effort began by asking a series of questions aimed at focusing the project. These questions included:

- How are rural roads defined?
- What types of accidents occur on rural roads?

- What IVHS technologies exist that can potentially reduce the number of accidents on rural roads?

Each of these questions is addressed in detail in this report. The remainder of this report is organized in the following chapters. Chapter 2 describes activities which focused the research project and provides additional background for the study. Chapter 3 discusses technologies available for a prototype ATIS introduced in chapter 2. Chapter 4 provides a cost analysis of the prototype. Chapter 5 presents a benefit analysis for the ATIS proposed here. Chapter 6 discusses sensitivity analysis. Chapter 7 takes a closer look at a simulation model developed to track vehicles and display their paths under minimum cost constraints. Chapter 8 contains the project conclusions and directions for future work.

CHAPTER 2

Preliminary Research

Defining Rural Roads

The definition of a rural road depends on the who is being asked. Some define roads by the area surrounding them. For instance, a rural road could be any road outside an urban area (location with a population of 50,000 people). This definition certainly coincides with state functional classification guidelines. Others define rural roads by the type of trip made on the road. So, for example, iterstates through rural areas are not considered rural roads since they typically handle long distance, high speed, intercity trips. Rural roads also are defined according to Average Annual Daily Traffic (AADT). In this case, roads are classified as low-volume and high-volume rural roads. Low volume rural roads carry 400 or less vehicles per day. High volume rural roads have AADT more than 400 and less than several thousand vehicles per day. Using this definition, an estimated 3.2 million miles of rural roads exist in the U.S. (Oglesby, 1985). However, many canyon roads in rural Utah have traffic volumes that exceed several thousand vehicles per day during winter and summer months. See Figures 1 and 2 for traffic volumes by month for Little and Big Cottonwood Canyons. These roads exceed thresholds for high volume rural roads under this definition. However, they are considered rural by state and local officials.

After considering many definitions of rural roads, we adopted the first definition, i.e., any road outside an urbanized area is classified as rural. However, we recognize that rural roads should be further classified to account for differences in accident rates and accident types on different types of roads.

Rural Road Accidents

The second issue confronted during this research effort dealt with developing an understanding of accidents that occur on Utah's rural roads. Analysis of historical accident data is required to identify the types of accidents occurring on rural roads. Before undertaking this analysis, however, our research effort included an extensive literature review aimed at answering two questions: (1) What approaches have others taken when investigating safety benefits associated with IVHS technologies?; and (2) What techniques and models have been used to analyze accidents, particularly in rural areas?

Developing an answer to the first question is difficult to achieve for two reasons. Although research on and implementation of IVHS have increased over the past few years, little has been published in peer-reviewed journals. Most of the literature exists as conference proceedings, unpublished research reports or as working papers. Several papers may be purchased from libraries of transportation centers, such as those in Texas and California. Also IVHS America is serving as a clearinghouse for IVHS research. Unfortunately, at the time of inquiry, this organization was unable to generate much relevant information. To expand on the third guideline issued by Lerner-Lam *et al*, (1992): "When you see the results from an IVHS system you implement and publish this information in sufficient, quantitative detail "to benefit others"."

The second reason that identifying approaches for evaluating safety benefits associated with IVHS technology is so difficult is that safety improvements have not been the principle focus of much of the IVHS research. Most efforts have been directed at reducing congestion through traffic monitoring, incident detection, vehicle navigation systems, and vehicle control systems. These systems are often evaluated in terms of reduced delay, headway, travel time, or volume. The added benefit of increased safety is frequently mentioned but not explored in detail. For instance, systems to minimize response time to accidents are expected to save the lives of victims. However, a secondary benefit - returning traffic flow to normal as quickly as possible - is often emphasized for reducing congestion caused by non-recurring incidents.

Exceptions in the literature, where approaches for measuring the impact of IVHS on safety are presented, is the work by done Hitchcock (1991) and Zhang (1991). Many in-vehicle systems, for braking and steering control and object sensors, are specifically intended to improve safety. Consequently, their benefits are typically measured in the number of lives saved or reduced accidents. Examples of IVHS projects in rural areas that use out-of-vehicle technologies and are designed specifically to address safety include a project in the State of Washington on a 40 mile stretch of I-90 (Judycki, 1992) and a project in Colorado on I-70 (WesternITE Newsletter, 1993). Presently, no information is available on projections for accident reduction for these projects.

After reviewing available literature, the following questions remain largely unanswered:

- How will IVHS technology improve safety?
- How many accidents will be avoided?
- How many lives will it save?
- Can the safety benefits of this technology be quantified?

Answers to these questions have serious implications for implementing the technology, particularly in fairly conservative states like Utah. IVHS represents a large capital expense that carries with it significant long term maintenance and operating expenses. Reliable models are needed to predict and quantify benefits of the technology to convince funding agencies to implement these systems. An alternative approach - build these systems and observe their impacts - works well for a limited number of applications over a long time frame. Furthermore, the argument that "place X has shown that these systems work well or pay off" is not always convincing to "place Y", as demonstrated by the slow progress of America toward implementing systems similar to those in Europe and Japan. A combination of well documented and monitored applications and predictive models are needed.

The question concerning techniques and models used to analyze accidents is somewhat easier to answer. An abundance of literature exists on safety studies. Most often, analyses consist of descriptive and inferential statistical methods. Regression techniques have been used to relate a suite of variables associated with accidents to the number or rate of accidents. Time series analysis also has been utilized to predict future accidents (Chang & Paniati, 1990).

The nature of this study necessitates a different approach to accident analysis. An objective of this study is to identify which technologies are appropriate for improving rural road safety. Many technologies may be appropriate for addressing certain types of problems and inappropriate for addressing other problems. A method for identifying accident types is needed to fit the right technology to the most appropriate situation.

Existing IVHS Technologies

The final step in the first phase of our research was to inventory and describe the types of technology used in IVHS applications. Within the next year, several Federally sponsored informational reports are forthcoming on emerging technologies. Some technologies have been presented in the literature as appropriate for the specific application considered here (Jacobs, et al., 1991; Sakagami, et al., 1992; Inigo, 1990; Yamin, 1991). However, to supplement the sparsity of detailed information, many manufacturers and vendors were contacted. Private sector contacts included companies selling satellite systems (GPS); telemetry systems (radio animal tracking and vehicle tracking technology); video systems; microwave communication systems; variable message sign systems; visibility sensors; pavement sensors and weather information systems. Also, companies using these systems, such as national trucking companies, were contacted. Once material on these technologies was compiled, electrical engineers were consulted to interpret information and enlighten the research team on the capabilities and limitations of the technology. This step is often enlightening for all parties. By asking "can we do this....with the technology?" or "how can we make this work?", the electrical engineers are challenged to integrate and modify technologies for new applications.

Refining the Problem

Summarizing information accumulated during Phase 1 of the project led us to the following conclusions:

- For both urban and rural applications of IVHS, little emphasis has been placed on quantifying safety benefits associated with proposed systems.
- Increased safety generally is a secondary benefit of most systems being implemented.
- Rural applications occur in corridors (usually on interstates) as opposed to having a regional focus.
- Rural applications are aimed at enroute drivers as opposed to pre-trip decision making.

- Additional benefits, other than safety, are not exploited in rural applications.

Two topics were identified through our initial effort for further study, namely, (1) to develop and test a model for identifying accident types on rural roads, and (2) to perform a cost-benefit analysis for a prototype ATIS described below.

The first topic is now part of an on-going MPC research project. The remainder of this report addresses the second topic.

Background of Study Area

Utah is a major tourist destination in the U.S. Its natural beauty and recreational facilities drew approximately 14 million visitors in 1991. These visitors spent $2.9 billion generating an estimated $163 million in state taxes and $51 million in local taxes (Utah Data Guides, 1992). As a result of this high number of tourists, the travel and tourism industry have become vital to the economic well being of the state. Every year, however, a significant number of travellers, both local and tourist, are involved in traffic accidents. Some of the factors contributing to such accidents include the following:

- Unfamiliarity with roads,
- Attention distraction due to scenic surroundings,
- Large vehicles pulling boats, cars, etc., on windy roads,
- Inclement weather, and
- Poor road conditions such as landslides, black ice, etc.

Traffic accidents during winter months are a major problem in rural Utah. Extraordinary costs are incurred, due to loss of life and property damage. Also many hours are wasted by stranded motorists waiting for tow trucks. Because of weather patterns, Utah experiences a high frequency of icing conditions on its roadways during winter. Accident data from the Utah Department of Transportation (UDOT) shows approximately 23 percent of all accidents at high accident rate locations occur during inclement weather, with 14 percent during snow and rain. Data shows the highest number of accidents occur during December, followed by November and January. The five year accident history for I-15 corridor between Salt Lake City and Brigham City also indicates the highest number of accidents occur during winter months. Accident data alone do not indicate the magnitude of this problem. During a typical storm, police, State Highway Patrol, and tow operators are kept busy responding to non-reportable (less than $100 damage) incidents.

Heavy recreational traffic on rural roads during the winter poses a substantial safety problem for Utah. A study done by French and Wilson (1992) on I-80 in neighboring Wyoming showed that, during a relatively short time period (9.8%) when road and travel conditions were poor, the study site had 61.1 percent of the total yearly accidents in the last five years. If accurate and reliable travel information is provided to motorists, perhaps fewer will risk travelling, or will travel with caution, and consequently, the potential for weather related accidents will be diminished (Piled & Wilson, 1992). According to Russam and Jeffery (1986), basic concerns of professional drivers are state-of-the-road and weather conditions. These are also important to other drivers for whom weather conditions might be sufficient reason for canceling or delaying a trip.

Proposed IVHS for Rural Road Safety

ATIS is a component of the Intelligent Vehicle/Highway System (IVHS) applications currently sweeping the nation. ATIS are information based applications designed to provide roadway users with accurate and timely information on travel conditions. A major assumption of these systems is that this information becomes factored into a person's decision on where to travel, when to travel, and how to travel (Khattak, et al., 1993). The purpose of many ATIS, both planned and implemented, is to mitigate traffic congestion problems by either, (1) informing an enroute driver of traffic incidents ahead and providing alternative routes or (2) allowing pre-trip travel decisions to factor in the benefits of delayed trip starts, or alternative routes and modes. The design of ATIS incorporates several technologies which are used to (1) collect data on current traffic conditions, (2) interpret this information, and (3) communicate it to the public. Most commonly used technologies include video, satellite, radio, and computers which, when integrated, become a complete traveler information system. Most rural systems are designed to provide information to a motorist on weather, road or traffic conditions ahead using visibility sensors, pavement sensors and variable message signs.

Several system design issues arise during the development of a rural ATIS. The prototype system described here differs from other rural applications of ATIS in the following ways:

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

A constraint we imposed on the problem of using IVHS technology to improve rural winter traffic safety concerned short term implementation. We recognize that much of the safety benefits of IVHS on rural roads will be found in automated vehicle technologies. However, when new equipment is required in individual vehicles, to send distress signals, warn sleepy drivers, etc., implementation will be long term, whether it is voluntary or mandated by law. Our interest was in analyzing a system that could be implemented by an organization, or group of organizations, in a short time frame.

An ATIS is proposed that monitors roadway conditions and uses dynamic mapping techniques to communicate this information to the public. A conceptual diagram of this system is shown in Figure 3. The potential market for this system is:

- tourists who stay in the urban areas and drive to different resorts during their vacation,
- resort employees who cannot afford the high cost of living in the resort communities so commute out from the city to the resorts,
- 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.

A component of this study is to develop a process to evaluate IVHS applications prior to their implementation. To evaluate the proposed ATIS, a specific region was identified within Utah (see Figure 4).

The study area includes several rural roads leading to ski resorts near Salt Lake City and Ogden, Utah. Ski resorts in the study area include (1) Sundance, (2) Snowbird, (3) Solitude, (4) Brighton, (5) Park City, (6) Deer Valley, (7) Alta, (8) Park West, (9) Powder Mountain, (10) Snow Basin and (11) Nordic Valley. Roads included in the study area, with their beginning and end mile points, are listed in Table 1.

Some of the roads contained in Table 1 are considered urban. These are I-15, part of S.R. 71, part of I-80, part of U.S. 89, part of S.R. 189, S.R. 52, S.R. 171, S.R. 181, S.R. 195, S.R. 203, S.R. 209, S.R. 215 and S.R. 266. Since the proposed ATIS application includes these roads, they are also considered, except I-15, in order to make the analysis complete.

The function of the ATIS is to provide drivers with real-time information on roadway conditions, incidents, and congestion caused by maintenance activities, etc. The system proposed here sends information about the current location of maintenance vehicles while they are plowing snow. This is accomplished by applying vehicle tracking technology.

A roadway management center (RMC) collects weather and surface information for different roads. Information may be obtained from many sources including maintenance crews engaged in plowing and salting roads. The National Weather Service and police may provide accident and weather information, too. Installing road surface sensors to cover the entire region is not proposed at this time due to prohibitive cost.

Cost analysis for this system assumes that only information about plowing and salting of roads during snowstorms, avalanches, drifting and icing conditions is sent from maintenance crews. As vehicles perform their duties, the paths of different snow plows are displayed on computer terminals. This enables RMC personnel to identify which roads are currently being plowed and present a temporal map of roadway conditions. This graphic data file is sent to different hotels, information centers, employment centers, etc. so that drivers may make decisions about their travel plans.

CHAPTER 3

ATIS Technologies

IVHS technologies are required for two components of the proposed ATIS, namely:

- to collect current locational data from remote sites, and
- to communicate roadway condition information to the public.

This chapter describes current technologies suitable for these functions.

Location-Finding Technologies: GPS

Developed by the U.S. Department of Defense, GPS uses a series of satellites and is designed primarily as a navigation system. At present, GPS is one of the world's best electronic distance-measuring devices. Currently, GPS uses satellite signals, accurate time, and computer programs to triangulate positions anywhere on earth 24 hours a day. It is based on a combination of 24 satellites orbiting the earth at a very high altitude. The satellites are high enough so they can avoid the problems encountered by land-based systems.

GPS deals with the interaction of three segments, namely space, user and control segments. The space segment consists of satellites. The user segment consists of the GPS receiver instrument and the control system acts as a device which converts signals from the satellites into digital data (e.g. latitude, longitude, elevation etc.). GPS is dependent on the availability of satellites for data capture, which is classified as 3-D or 2-D. 3-D involves four satellites providing latitude, longitude and altitude data over time and 2-D involves three satellites providing latitude and longitude data over time.

Although GPS technology can locate in real-time vehicle position with latitude, longitude, and altitude, this locational information must be sent to a control center for data integration. Within the last two years, a unique two-way mobile satellite communication and tracking system has been introduced to the trucking industry in the United States and Europe. The system operates on the 12/14 GHz band (Ku band) which was allocated to the Fixed Satellite Services (FSS) on a primary basis. The system uses a pair of Ku-band transponders on a domestic FSS and can serve 40,000-80,000 user terminals depending on the average length of message to be transmitted and the frequency of transmission (Jacobs, et al., 1991). Terminals can be installed in vehicles ranging from 18-wheel tractor-trailers to passenger cars.

The Ku-band, mobile satellite communications network has three major components, which are:

1. A Network Management Facility (NMF) for controlling and monitoring the network.
2. Two Ku-band transponders, a U.S. domestic satellite located at 103 West Longitude.
3. Two-way data communication and position reporting mobile terminals.

The NMF contains a 7.6 meter earth station including modems (HUB) to communicate with mobile terminals via satellites and a Network Management Center (NMC). The traffic message passes through the NMF. The HUB facility has forward link and return link processors which are hardware/firmware subsystems developed specifically for this system. These are used to send messages from the NMF to mobile terminals on vehicles and vice versa. The duties of the NMC include network monitoring and control, message formatting, processing, etc. The NMC has a connection with Customer Communication Center (CCC). The whole system is capable of two-way data messaging, position reporting, fleet broadcasting, etc. (Jacobs, et al, 1991).

The system uses two transponders in a single Ku-band satellite. One transponder is used to send a continuous data stream from the Hub to all mobile terminals in the system at a rate of 5-15 kb/s or more. Messages are addressed to individual mobile terminals through the forward link. A second transponder on the same satellite is used by the return link. Each mobile terminal sends data at the low rate of 55 to 165 b/s.

For two way communication, a mobile terminal is needed in each vehicle. It consists of three components: the outdoor unit, the communication unit and the display unit. The mobile terminal can operate in temperatures between -30°C and 70°C. For the purpose of our study, one-way communication is required since only locational information from the maintenance vehicle will be sent to NMF. In this case, the display unit is not required and the communication unit will be much simpler. It may use infrared beacon, RF (UHF/VHF), cellular telephone, satellite, or FM sideband data communication link to connect the mobile units with the dispatch center. At present the maintenance vehicles are using RF for communication purposes.

Each type of communication link has its own advantages and disadvantages. Table 2 compares some of the characteristics among different types of media (Kirson, 1991). From this table, it is evident that the RF data and Satellite Services networks are the most useful and efficient communication links.

The outdoor unit of mobile terminal continuously monitors signals from all satellites in view and provides reliable accurate tracking data. It is basically a 6-channel GPS receiver. Locational data captured by the outdoor unit may be sent from the vehicles to the NMF through any type of communication link. Currently, there is no NMF in Salt Lake City. The NMF in California sends this position data to RMC in the proposed study area via 486 PC. It is estimated by QUALCOMM Inc. that about $1200 worth of equipment is needed in each maintenance vehicle for one-way communication. This cost is almost the same as that provided by Trimble Navigation Company for the trucking industries. Also there is a cost of $50 per vehicle, per month to use satellites for data communication.

Accuracy is an important factor in vehicle tracking. In other applications, GPS can usually locate the position within a few meters of accuracy using differential modes, but this is not the case for tracking when the vehicle is moving. QUALCOMM Inc., who is using GPS for vehicle tracking, reports a tracking accuracy of approximately 300 feet, which is not very precise. According to Trimble Navigation Inc., however, location accuracy may be within 15 meters. The accuracy of GPS depends upon the following factors:

1. Problems of satellite visibility may occur in forest areas, urban settings or near mountains. GPS signals are low power and require a direct line of sight to the on-board GPS receiver.
2. According to Kavanagh (1989), the main sources of error in GPS are:
    - Multiple interference due to the fact that some signals are received directly and others are received after reflecting off adjacent features.
    - Ionospheric and atmospheric refraction.
    - Errors associated with the satellite orbital data.
3. Zilkoski and Hothem (1989) mention that atmospheric refraction, ionospheric and tropospheric conditions, orbital coordinate data, different antenna design, multi-path effects, misidentified bench mark, etc. may affect the accuracy of GPS based data.

Coco et al. (1991) also state that GPS signals are significantly affected by the troposphere and ionosphere layer of air. The ionosphere acts as a dispersive medium to GPS signals but the troposphere is nondispersive. Ionospheric propagation delays can be removed by the use of two frequencies, but this is not possible for tropospheric delays. The troposphere introduces a delay to the GPS signals of about 2 meter in the zenith direction and 20 meter at 5 degree elevation. This tropospheric delay may occur in both dry and wet parts of the atmosphere. The GPS satellites usually broadcast two frequencies (L1 at 1575.42 MHz and L2 at 1227.60 MHz) to allow the users to remove ionospheric delays. However, these two frequencies are not always available to all users. All of the GPS-coded signals undergo a group delay when they pass through the ionosphere. This group delay can be as large as 30 meter for L1 in the zenith direction and much more at low elevation angles.

Another significant limitation of GPS is that it is a navigation system that resolves location in the vehicle. The central management facility needs location data. To transmit this location data, GPS must be linked to some data communication system, possibly digital radio. For a large corridor where hundreds of vehicles are operating simultaneously, several expensive radio channels are needed which will add considerable cost to the capital. However, the sampling algorithm developed to track vehicles in dynamic paths will minimize the required number of radio channels (O'Neill, et al., 1993).

Radio Communication Systems

Vehicle tracking by radio communication systems is considered to be better than satellite communication system due to the following considerations:

1. Propagation delay time of land mobile communication is negligible compared to that of satellite communication,
2. Cost of a radio-tracking system is less than that of a satellite system.

The following general model is used for the radio tracking system (Murase & Imamura, 1987):

1. Signal access from each vehicle is controlled by a central station.
2. A central station and all other vehicles are connected by different channels.
3. An infinite number of vehicles can be connected with the central station.

According to the model, each snow plow assigned to certain road segments has a transmitter mounted on the vehicle to transmit a signal in a certain frequency. This signal is picked up at two base stations. The base stations measure the time of arrival and forward it to the Network Computer Center (NCC). The NCC triangulates the position of vehicle with the help of angle-of-arrival (AOA) or distance of incoming waves and sends this data to the RMC (Sakagami, et al., 1992). More base stations can be used to obtain more precise locations. Using a computer, this position is matched to a digitized network in the RMC and shown on a road map. A data base containing the entire road map has previously been stored in the computer.

This system has an advantage in that it can be used as a communication system as well as position location system at the same time. A network is installed, including a centrally controlled array of base stations with overlapping communication areas, mobile radio modems in vehicles which function as radio-ranging transponders, data modems, radio transceivers, and a Network Computer Center (NCC). The NCC coordinates the operation of all the base stations and radio modems within radio-communication range of the base station network. Currently Pin-Point Communication Inc. is developing this type of system in urban areas for vehicle tracking.

The NCC is a regional or metropolitan system hub. It controls and maintains all communications and navigation functions. It has communication with base stations. The base stations receive the signal from a vehicle, measure its time of arrival and forward it to the NCC. Thus, it receives the radio modem location timing from base stations every time the radio modem in the vehicle transmits data. NCC then computes the location of radio modem by the triangulation technique, organizes transmissions of the data packets and communicates with the RMC. An array of base stations with overlapping coverage need to be installed in the proposed study area. Base stations communicate with the mobile radio modems and are connected to the NCC. Communication of radio modems with base stations is done using a proprietary radio technology. This type of network can accommodate up to one million users in a metropolitan area (Taylor, 1992).

The ideal spacing between base stations is 10 miles and each station covers a five-mile radius (Taylor, 1992). However, this does not account for the effect of terrain, high mountains, tall buildings, etc. In these areas, the spacing will be less than 10 miles. The proposed study area is about 70 miles long and 30 miles wide. Thus it needs a minimum of 7*3 = 21 base stations.

An in-vehicle modem costs around $300.00. The cost of each 22-character data packet is $.005 to $.01. However, in our present study, this cost is negligible since only location data from the vehicle is sent. The access fee for each vehicle is $10 per month for up to 2000 position fixes.

The accuracy of vehicle position from such a signal system is an important factor. D'Andrea, et al., (1990) mentioned that tracking error depends on energy-per-bit to noisepower-density ratio E_b/N_o. Error decreases with increase of E_b/N_o. It may be of the order of 20 feet to 200 feet depending upon distance from the receiver, terrain conditions, etc.

The location accuracy of this radio technology mentioned above is very good. It can locate the position of the vehicle within 2-5 feet with direct line of sight. Without line of sight, the signal is scattered and the accuracy is within 20 to 50 feet which is still usable in an urban setting (Taylor, 1992). Data can be communicated at a much higher rate than with a satellite communication link. The transmission rate may be on the order of 400,000 bytes per second.

The main disadvantage of this system is that the user needs a personal computer plugged into the vehicle's radio modem or a small in-vehicle mobile data terminal to send and receive messages from the NCC. The snow plow operator has to press a button to send location data, which is not desirable. Computer software is needed which automatically determines the time to send the signal in a non-fixed interval thus eliminating human involvement. This software reduces the number of signals sent from the vehicles (O'Neill, et al., 1993). The various elements of the system should be time-synchronized to reduce location error and cost of the network. Thus the cost may be closer to $1000 per vehicle with additional equipment.

Communication to Fixed Sites

After receiving locational data at the RMC from different vehicles either by GPS or radio technology, road condition information is sent to different locations such as hotels, information centers, etc. The following computer equipment is needed to send data files from the RMC:

1. 9600 baud modems, one in the RMC and one at each of the other locations. 14400 baud modems can also be used for faster data transfer.
2. One IBM or Intergraph 6000 work station with a c400 processor at the RMC.
3. One IBM 486 PC at each location.

These data files are sent through existing telephone lines. Service fees are similar to telephone bills. Interactive graphic displays at the remote sites, communicate current road conditions, allow travelers to identify clear routes between their origin and destination, and may possibly communicate other information typically available at travel information kiosks (in restaurants, services, etc.).

CHAPTER 4

Cost Analysis of Proposed ATIS

Cost Model

Exact cost of the proposed system is difficult to determine. A cost estimate may be derived based on a few simple assumptions. 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 that 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 only during the winter months, from November to March, despite its potential year-round utility.

Present Worth of Cost (PWOC) is calculated from the following equation (NCHRP, 1975; Department of Veterans Affairs, 1989; Abelson, 1979):

$$PWOC = I + \sum_{j=1}^{n} A\ PW_j - T\ PW_n$$

where I = initial cost

$$\left(\sum_{k=1}^{8} IC_k\right)$$

IC_k = initial cost of item k

A = annual cost

$$\left(\sum_{k=1}^{5} a_k\right)$$

a_k = annual cost of item k

T = salvage value

PW_j	=	present worth factor for year j
	=	$1/[(1+r)^j]$
r	=	discount rate = 7%
j	=	1 to 10 years

Cost analysis of the proposed ATIS considers both GPS and radio technology for tracking locations of maintenance vehicles.

Non-recurring Costs

The first step in estimating 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. These one-time costs include such items as system design, programming, system testing, equipment acquisition, training, etc. These costs may occur at any time during the life cycle of the system. For the sake of simplicity, an assumption is made that non-recurring costs occur only during the first year of the cycle. Table 3 shows initial (non-recurring) cost estimates for this model. The following assumptions are made in deriving these figures.

Cost of Roadway Monitoring Center (RMC). A centralized roadway management center 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 upon 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 $1200.00 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 $1000 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, several years delay can be expected before it is available in rural areas.

Eighty-four (84) 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 per vehicle cost.

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

1. IBM, Intergraph 6000 or equivalent work station with a c400 processor in the RMC. This is an initial cost which is estimated at $8000.
2. IBM 486 PCs, one at each remote site for graphic display of road conditions. The memory of each PC should be at least 30 megabytes. There are more

than 60 hotels and motels in and around Salt Lake City where visitors stay during winter months. If 50 of these and ten information centers (resorts, malls, employment centers, etc.) are considered for display of roadway conditions during snowy weather, at least sixty 486 PCs are required for this study. (It is not possible to sell this system as a service to these remote sites since information is being gathered by the state, and therefore, public.) Cost is calculated per unit site. Each 486 PC costs about $3200 including a monitor.

3. 9600 or 14400 baud modems. One at the RMC and one at each other location. Each modem cost is $200.

4. The software includes micro-station 32 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 $1000 per site.

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 $2800. Another approach uses a videoverter hooked to the computer and a color television to show the map display on a large T.V. screen. The cost of this equipment is $399 excluding T.V.. So total cost will be $2100 including a large T.V. which is less than the previous kind mentioned. Another approach, 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. This equipment is considered in the present study. Touch screen interactive capabilities adds approximately $335 to the cost of each remote site monitors.

Recurring Costs

The second step in the cost estimation process is to determine recurring costs (annual costs) which are costs associated with maintenance and operation of the system. Data communication costs, personnel services, space occupancy, supplies and utilities, etc. are examples of recurring costs. Table 4 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. Both people are paid a gross amount of $3000 per month in the first year. A five percent increase in the salary is assumed for subsequent years.

Purchase Cost of road network database: A graphic based system is proposed that uses maps to convey road condition information as well as accident and weather information. This spatial database must contain roads in the region to accommodate interactive queries by users on optimal routes. An updated road network database may be purchased from a private organization each year due to construction of new roads, or closing of existing roads. UDOT, itself, may be able to supply this data, so base map update costs could be insignificant. However, it is assumed that an amount of $2000 is required each year to purchase this 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 (most during peak hour, least 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 upon the weather. A plowing period may not be more than two hours, because it is Utah's policy to clear snow from roads within two hours. However, in case of continuous snow, this period may be much longer. In the present study, a snow removal period is taken as 8 hours a day. There are 152 days from November to March. A ten year weather history from Utah Climate Center indicates that it snows more than a half inch in the study area for an average of 24 days during this period. Maps at remote sites are updated every 15 minutes. In an 8 hour period, data transmission occurs 32 *60 times. Assuming 15 seconds per site to send information, it will take 480 minutes per day. Using a cost of $.20 per minute, total cost per day is $ 96, or $2,304 per year.

Maintenance Cost at Remote Sites: Each facility where current roadway conditions are shown has potential maintenance needs, due to hardware failure, vandalism, etc. This maintenance cost is estimated to be $1000 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, reutilized, or continue in operation for another cycle. If the asset is sold or reutilized, the value is the actual market value less costs of sale or redistribution. If the asset is to be scrapped, the only value is the scrap value less costs of dismantling and selling. In this study, all hardware and software is considered to be dismantled after 10 years for the sake of simplicity. The salvage value of the proposed ATIS is considered to be zero after 10 years, as a conservative approach.

During the next 10 years, new technology is expected to become available that can be incorporated into the system. The ATIS described here may become obsolete at that time. However, the basic principal will be almost the same with the addition of some new features.

In the cost analysis of both GPS and Radio technology for the next 10 years (from 1993 to 2002), all cost estimates for each year have been made in current dollar value. A discount factor of 7 percent is considered here 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 (Abelson, 1979; Sassone & Schaffer, 1978).

Results of the Cost Analysis

Present worth of cost for the ATIS using GPS and radio-based technology is shown in Table 5. The number of remote sites receiving this service is assumed to be sixty (60) in this analysis. It appears from this analysis that the radio technology will cost slightly less than the GPS technology over a ten year period. However, these figures do not take into account the cost associated with delayed implementation of the system using radio-technology. The GPS design may be implemented almost immediately whereas a sufficient radio network must be installed prior to implementing a radio-based tracking system.

CHAPTER 5

Benefit Analysis of Proposed System

Benefits Analysis

IVHS is claimING to have various benefits, including the reduction of congestion, pollution, energy consumption, and accidents, and improving mobility. An additional benefit of the ATIS proposed here is improved data for winter maintenance management. To follow a conservative approach, benefits due only to reduction of accidents are considered.

Accident data for different roads leading to ski resorts are used in this analysis. Only accidents that occur during winter months in snow and icy/wet conditions are selected from the database. A shortcoming of this data is that it does not provide information on delays by stranded motorists (waiting for tow trucks) stuck in heavy snow during bad weather. In these incidents, there is typically no damage to vehicles or drivers. However, lost time and towing expenses result from these, all to frequent, situations. Historic trend information is used to estimate the number of future accidents in the study area if the proposed technology is not implemented.

Accurate estimation of benefits resulting from implementation of this technology is difficult, due to the following potential responses from drivers:

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, employment centers, etc. 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, due to importance of their trip or lack of confidence in the system or technology. Lack of confidence due to technology breakdowns will lead to possible future disregard of available information. Lack of confidence in the system, however, caused by obtaining inaccurate or outdated information, will lead drivers to distrust all such information in the future. These drivers will then be classified in Category 1, above. Accident potential for drivers in Category 2 will not change.

3. Some drivers will use the information provided by the system. It has been found that informed drivers travel more cautiously or cancel trips (NCHRP, 1991; Piled & Wilson, 1992). In this case, the following three conditions may result:

   - Drivers will proceed cautiously and/or avoid hazardous routes. This will reduce accident potential.
   - Drivers will delay trips. Chances of becoming involved in an accident are less but it is difficult to estimate potential accident reduction.
   - 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 behavior/reaction to proposed ATIS need to be conducted in hotels and other appropriate locations. Due to resource limitations, however, such surveys are not conducted in the present study.

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

Analysis of Data

Accident data for the five months from November to March over a five year period from 1987 to 1991 was analyzed. During this period, accidents only during snow, snowstorms, etc. have been considered in the analysis to relate the number of accidents with snow-removal activities.

Despite the availability of data from UDOT in various files, there is a problem of quality and completeness of data. Accident data files must be integrated with traffic and road inventory data for this analysis. No data are available for three roads in the study area during 1987. Unfortunately, Average Annual Daily Traffic (AADT) data on some roads are not consistent at all.

Other research using accident databases have indicated that other problems with this data occur. For instance, not all reported accidents are submitted, particularly in urban areas where property damage 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 multi-vehicle 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 (Brinkman, 1986).

The interrelationship of various accident causal factors makes data analysis and interpretation difficult. Usually, the number of road accidents should have some relation with traffic volume. Several studies show that this relation is more complex than a simple proportion (Frantzeskakis, 1983). In this study area, AADT is analyzed separately both for rural and urban roads for the last five years from 1987 to 1991. Each road is found to have several sections with different AADT. 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 length. Percent change in AADT for the last four years is determined separately both for rural and urban roads. No general pattern is identified from these calculations. This may be due to bad data or because of uncertain behavior of travellers along those road segments. Due to lack of trend in AADT change, only the number of accidents is analyzed for the purpose of future prediction of accidents.

Accidents on rural and urban roads are analyzed separately due to the fact that the manner of occurrence of traffic accidents varies greatly in these areas. Accidents can be classified into various categories depending upon severity, causes of accidents, types of collision, etc. Accidents have been classified into five types based on severity according to a FHWA study (FHWA, 1991):

1. Property Damage Only (PDO): Only those accidents in which damage to the vehicle or roadside property results.
2. Minor Injury: Only those injuries which need minor treatment such as abrasion, pain, nausea, hysteria etc.
3. Medium Injury: It includes lump on head, minor lacerations, bruises, crushed finger, etc.

4. Serious Injury: Any injury other than fatal injury, which prevents the injured persons from walking, driving, or doing normal activities.

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, etc. In the present case, analysis is done according to number of various types of accidents based on severity. Table 6 summarizes the number of PDO, minor injury, medium, serious, and fatal injury accidents, respectively, on rural and urban roads during snow, snow storm, etc. in the winter months for the last five years. While there is no uniform pattern for number of accidents in separate road segments, an increased pattern is observed for total accidents in the last five years.

An average of 10 percent increase in accidents occurred in the last five years for rural roads. This figure (10%) is used to estimate future increase of accidents in rural roads. An average of 31 percent increase in accidents on urban roads occurred over the last five years. In this study, an average increase of 10 percent is considered for future prediction of urban accidents to be conservative.

Table 7 shows percentages of different types of accidents with respect to total accidents for rural and urban roads. A one way ANOVA test was conducted to determine if the percentages of various accident types among different years are 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% of accidents are PDO, 12.64% are minor, 7.5% are medium, 6.75% are serious and .28% are fatal injury accidents for rural areas. For urban roads in the study area, it is assumed that 71.64% of accidents are PDO, 15.33% minor, 7.55% medium, 5.24% serious and .24% are fatal injury accidents.

Assuming a ten percent annual increase in the number of accidents in the study area, total accidents for the next ten year period may be calculated (Table 8).

Analysis of Safety Benefits

Safety benefits vary from year to year throughout the service life due to variation of 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 (NCHRP, 1975; Department of Veterans Affairs, 1989; Abelson, 1979):

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

where B_n = Benefit varying from year to year
PW_n = Present worth factor
= $1/(1+r)^n$
r = 7%

Safety benefit B_n is estimated from the following formula (NCHRP, 1975):

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

where N_f = Total number of expected future accidents
P_i = Percentage of accidents of type i
S_i = Expected reduction in type i accidents
C_i = Average cost of type i accidents

Now the problem boils down to estimating expected reduction of 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' reaction as mentioned before. It may vary for different types of accidents such as greater reduction in fatal accidents as opposed to PDO. To simplify the estimate, accident reduction is considered to be uniform for all types of accidents.

To complicate the analysis further, methods used to determine costs for different accident types are not standardized yet. Average cost of various types of accidents vary according to different organizations. Cost estimates are composed of various components such as wage loss, medical expenses, insurance administration costs, motor-vehicle repair/replacement costs, etc. According to National Safety Council (1992), the estimated costs for different types of accidents in 1992 is given below:

Fatal Injury	$450,000
Serious Injury	42,400
Medium Injury	10,700
Minor Injury	3,300
PDO accident	1,100

These costs are used in the benefit analysis. Given the assumptions and data described above, safety benefit is calculated such that $S_i = S_j$ for all 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 shown in Table 9.

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 up-to-date 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 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 is not considered in the present study.

CHAPTER 6

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:

NPV = PWOB - PWOC

B/C ratio = PWOB/PWOC

Table 10 shows the value of these statistics for the proposed system at different accident reduction rates. NPV is positive and B/C ratio greater than one when the accident reduction rate is 2 percent or more. The break-even period for different accident reduction rates is shown. With a 2 percent reduction in accidents, the GPS-based ATIS would pay itself off in nine years. This figure decreases significantly with a 3 percent accident reduction rate.

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

The variables considered in the sensitivity analysis are: (1) staff salary, (2) GPS instrument cost, (3) telephone fee for data transmission, and (4) the discount factor. The relative sensitivity of these variables, for ±20 percent variation is shown in Figures 5 and 6 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.

In the study, both GPS and radio systems are found to be cost-effective when the accident reduction is as low as 2% for all types of accidents. Sensitivity analysis of the cost variables indicates that the NPV is still positive with more expensive hardware than used in the study.

Only benefits due to accident reduction are considered here. However, there are other non-monetary benefits of this system which 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 costs each year and provide improved data for effective forecasting and decision-making. The system would be more cost-effective than shown here.

A survey on travellers' behavior should be conducted to understand their perspective if this type of system is implemented. This survey will help estimate the percentage of travellers using system information to change their route or delay trips. This behavior may provide better information to estimate percentage reduction of accident.

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

CHAPTER 7

Simulation Model

A main component of the prototype ATIS is the dynamic mapping system used to track maintenance vehicles and display roadway conditions to the public. Several issues arise regarding the design of this component. One issue deals with base map design and location finding technologies. A second is concerned with location sampling algorithms. A third deals with image interpretation and communication needs. This chapter focuses on the second issue, regarding vehicle tracking algorithms, and describes a simulation model developed to allow computers to automatically track maintenance vehicles.

Model Description

Currently, maintenance vehicles are equipped with two-way radio communication. It is feasible for operators to radio in their location at regular intervals so their paths can be constructed. However, several problems exist with this approach. First, location information is to be tracked on digital maps so that each road can be assigned a color indicating when it was last serviced. An operator's verbal description must be matched to a graphic image described by latitude and longitude coordinates. If an operator uses a route-milepost description (i.e. SR 89, milepost 134), then the mapping system must be capable of converting this information to the underlying coordinate system. Much has been written on the complexities of converting between location-referencing systems (NCHRP, 1975). Another complication is the fact that rural roads often have many names. For instance, a road between Brigham City and Logan in Utah is known as SR 89, SR 91, Sardine Canyon, and Wellsville Canyon. Finally, operators are often working under hazardous conditions - poor visibility, slippery roads, reckless drivers trying to pass them, accidents and stranded vehicles blocking their path. To add the burden of maintaining regular contact and providing accurate location information is unnecessary given the technology available today.

Many technologies exist for identifying vehicle locations. The most common is Global Positioning Systems (GPS) which use satellite technology to identify locations on the earth. These systems have been applied by national freight carriers to track truck movements throughout the U.S.. An ongoing debate on the accuracy of GPS systems focuses on the following issues - signal distortion in urban areas caused by tall buildings and in rural areas by mountains, signal distortion during bad weather conditions. Other technologies being marketed include radio and microwave based systems. Whether satellite, radio or microwave technology are adopted, companies providing these systems generally charge an installation fee and a monthly service charge. The service charge often is a function of the number of times the service is used (similar to cellular phones). Each time a location is sampled constitutes service. When several hundred vehicles are operating simultaneously, service requests can quickly incur excessive costs. The number of times a service is utilized also impacts the required capacity of the system. Consequently, to minimize the costs (and capacity) associated with tracking systems an algorithm has been developed that tracks vehicles along dynamic paths.

Model assumptions are:

- an operator's route is not fixed or known with certainty prior to his trip (in rural areas, operators are sent where demand arises - they may even assist with county operations if needed),

- at most, location information is requested once per link, where a link is a section of road between two intersections representing a possible change in travel direction.
- Operators may not turn around (reverse direction) on a link.

Input data for this model are:

- a link/node structure as described above,
- link attributes--average speed, type of traffic control (stop, yield, signal, none),
- parameters (mean, standard deviation) for probability distributions for delay at intersections. (ex. movement - left turn at a stop sign, sample from a normal distribution with mean equal to 8 seconds and standard deviation equal to 3.5 seconds).

Unlike vehicle navigation systems where location information is used to answer, "Where am I?" and "What is the best way to get where I am going", this algorithm is intended to identify where a vehicle has been. If there is more than one node separating location sample points, then a true path cannot be constructed (see Figure 7A). However, sampling at a fixed interval, determined from the overall minimum time to traverse a link in the system, is wasteful (see Figure 7B).

Vehicle Tracking Model Algorithm

A description of the algorithm is given for a single vehicle, however the system will track several hundred vehicles at one time. A flow chart for the basic model is shown in Figure 8. As a vehicle leaves the shed, time is initialized to zero. All downstream (candidate) links are identified using network topology information. The time to sample

$$T_s = t_i + \min\{\ at_j + t_{p_j}\ ,\ at_k + t_{p_k}\ ,\ at_l + t_{p_l}\ \}$$

where:

t_i	=	time to traverse remaining section of link i,
t_j, t_k, t_l	=	time to traverse link j, k, and l,
a	=	parameter between .25 and .75 which guarantees that sample location will not be so close to an intersection that it is difficult to identify on which link a vehicle is traveling,
t_{p_j}, t_{p_k}, t_{p_l}	=	turn penalty for link j, k, l.

A video has been produced describing this simulation model in detail. This video is available through the Utah Transportation Center. The simulation model described in this chapter has been tested in a laboratory environment. Further testing is required in a real environment. These test will use GPS devices mounted in vehicles. Also, parameters needed to determine turn delay must be calibrated under realistic operating conditions. We can then use the model to track vehicles in the mountains during adverse weather.

CHAPTER 8

Conclusions

A research study was conducted to investigate the potential application of Intelligent Vehicle/Highway Systems (IVHS) technologies for reducing accidents on rural roads. After studying existing technologies, their present application to transportation, and approaches to identifying predominant accident characteristics, a prototype Advanced Traveler Information System (ATIS) for a rural region was developed.

A significant proportion of all accidents that occur in rural areas are winter weather accidents. The situation is aggravated in states, like Utah, that attract many out of state tourists for winter recreational activities. An ATIS is proposed that (1) serves a large region, as opposed to a single corridor, (2) provides pre-trip travel information, as opposed to en route information , and (3) provides current information on road condition.

A cost-benefit analysis of the proposed ATIS has been conducted. Two technologies, namely satellite and radio, are explored for providing location information for maintenance vehicles. These vehicles can be tracked by a roadway management center. Location data are used to create a temporal map indicating when roads were last serviced (plowed, salted, etc.). Additional information on accidents, avalanches, road closures, etc. are added to this database at a central Roadway Management Center (RMC). Current roadway information is then transmitted to remote sites, in malls, hotel lobbies, resorts, major office buildings, etc. for travelers to consult prior to taking a journey. Television may also be used as a medium of communication for current roadway data. Hardware, software, and labor costs are used to estimate cost of the ATIS.

Benefits of the system are savings resulting from reduced accidents. Unfortunately, traveler's use of these systems has not been studied sufficiently. It is difficult to predict how many people will benefit from the information by either delaying a trip, selecting a safer route, or driving more cautiously. Consequently, the benefit analysis conducted here involved: (1) analyzing historical data on winter weather accidents that were stratified by severity, (2) predicting the number of winter weather accidents by severity that would occur during a ten year period if the ATIS were not implemented, and (3) determining the amount of savings that would be incurred if the system were effective in decreasing the number of winter weather accidents by a certain percent. An additional benefit, that has not been quantified in this report, is collection of an accurate and comprehensive database on maintenance activities for use in planning and budgeting future needs.

The cost -benefit analysis indicated that the net present value of the ATIS is positive with an overall 2 percent reduction in winter weather accidents. Further, with a 2 percent reduction in accidents, the system pays for itself in nine years. This number decreases significantly with a 3 percent accident reduction. Sensitivity analysis was performed to determine the stability of the model.

Finally, another component of the research effort was to develop a simulation model to track maintenance vehicles such that cost is minimized. Generally, location finding technologies are not very accurate in mountainous terrain and under adverse weather conditions. Further, most technologies have a fee associated with their use, based on the number of times a location is requested. A third factor in development of the simulation model is that maintenance vehicle's routes are dynamic. Vehicles respond to current needs and are sometimes used to assist with county and local operations. Finally, commercially available vehicle location/navigation packages are not designed to identify paths over which a vehicle has traveled. The question they address is, "What is the current location of the vehicle?". The ATIS application described here requires that each vehicle's path be identified in order to communicate temporal information on when a maintenance vehicle last plowed/salted a road. The simulation model developed in this study has been tested in a laboratory environment. Further testing is required in a real environment by mounting GPS devices in vehicles and using the model to track vehicles in the mountains during adverse weather.

Future Efforts

As mentioned in this report, there is an on-going research effort to develop a model that identifies accident types or clusters. Once we characterize accidents by either location features or accident characteristics, we will be able to address the broader question regarding the use of all IVHS technologies to improve rural road safety. More importantly, we will have improved capabilities for evaluating the benefit of implementing these technologies.

Other research that is needed with regard to the ATIS described here is, (1) implementation, testing and refinement of the simulation algorithm for tracking maintenance vehicles in mountainous terrain and adverse weather, and (2) investigation into organizational requirements and constraints to implementing a rural regional ATIS. Many agencies are involved in the successful implementation of a system, such as the one described here. Cooperation and coordination among state and local agencies is needed. Participants include the DOT, state highway patrol, local governments and private entities, such as mall, resort, and hotel owners. Strategies for implementing these systems to achieve interagency cooperation and coordination must be developed.

Finally, more research is needed to understand people's acceptance and use of these systems. Even if the philosophy for implementing IVHS technology is that users will eventually accept and use it, we must be concerned with the design of these systems to increase their potential for use as well as their utility. For instance, many issues related to human factors have been investigated for on-board vehicle navigation systems, including the how to give people directions (verbally, symbolically, as maps, etc.). We need more research to determine how to provide access to rural road condition information (TV, phone, kiosk, radio, etc.), what other pre-trip information would be useful to local and tourist rural road travelers, and how the information is being interpreted and used by people.

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TABLES

Table 1. Roads included in study

Name of Roads	Beginning Mile Point	Ending Mile Point	Name of Roads	Beginning Mile Point	Ending Mile Point
I - 15	268.00	349.00	S.R. 166	0	5.95
S.R. 39	7.75	25.66	S.R.167	0	9.29
S.R. 40	0	30.00	S.R. 171	0	15.62
S.R. 52	0	4.54	S.R. 181	0	6.88
S.R. 65	0	28.10	S.R. 181	0	29.16
S.R. 66	0	13.99	S.R. 190	0	20.03
S.R. 71	0	20.04	S. R. 195	0	2.57
S.R. 74	0	5.65	S. R. 203	0	6.12
I - 80	115.00	177.63	S. R. 209	0	14.6
S.R. 84	80.37	119.72	S. R. 210	0	13.72
U.S. 89	264.1	325.01	S. R. 215	0	28.98
S.R. 92	0	27.12	S. R. 224	0	21.6
S.R. 113	0	7.11	S. R. 226	0	7.68
S.R. 146	0	5.34	S. R. 248	0	14.42
S. R. 162	0	7.32	S. R. 266	0	8.09
S.R. 165	0	10.73			

Table 2. Comparison of characteristics among different types of media

Type	Infrastructure Cost	Vehicle Cost	Throughput Capacity	Type of Communication	Geographic Coverage
Infrared Beacon	High	Low	High up to 1 Mb/s	2-way	Small per beacon
RF Data Network	Low	Medium	Med to high 19200 b/s	2-way	Complete
Cellular Telephone	Low	Medium	Medium	2-way	Limited
Satellite Service	Low	High	Medium 2400 b/s	2-way	Very wide
FM Sideband	Low	Low	Low 1185 b/s	1-way	Limited

Table 3. Non-recurring 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

Table 4. 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 Radio access fee	a_3	$ 50,400 $ 10,080
Telephone fee for remote sites	a_4	$2,304
Maintenance cost at remote sites	a_5	$ 60,000

Table 5. Cost analysis of ATIS over 10 years

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

Table 6. Total accidents during winter months and snowy conditions in the 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

Table 7. Percentages of accidents by type and year on rural and urban roads in the study area (numbers are rounded to the nearest tenth)

	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

Table 8. Estimated number of accidents during winter months and snowy conditions on rural and urban roads

	1992	1993	1994	1995	1996	1997	1998	1999	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

Table 9. 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 10. Cost-benefit statistics for proposed ATIS

System	**NPV**	**B/C Radio**	**Break-even point**
1% accident reduction			
GPS	-876,693	.52	NA
Radio	-567,701	.62	NA
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

FIGURES

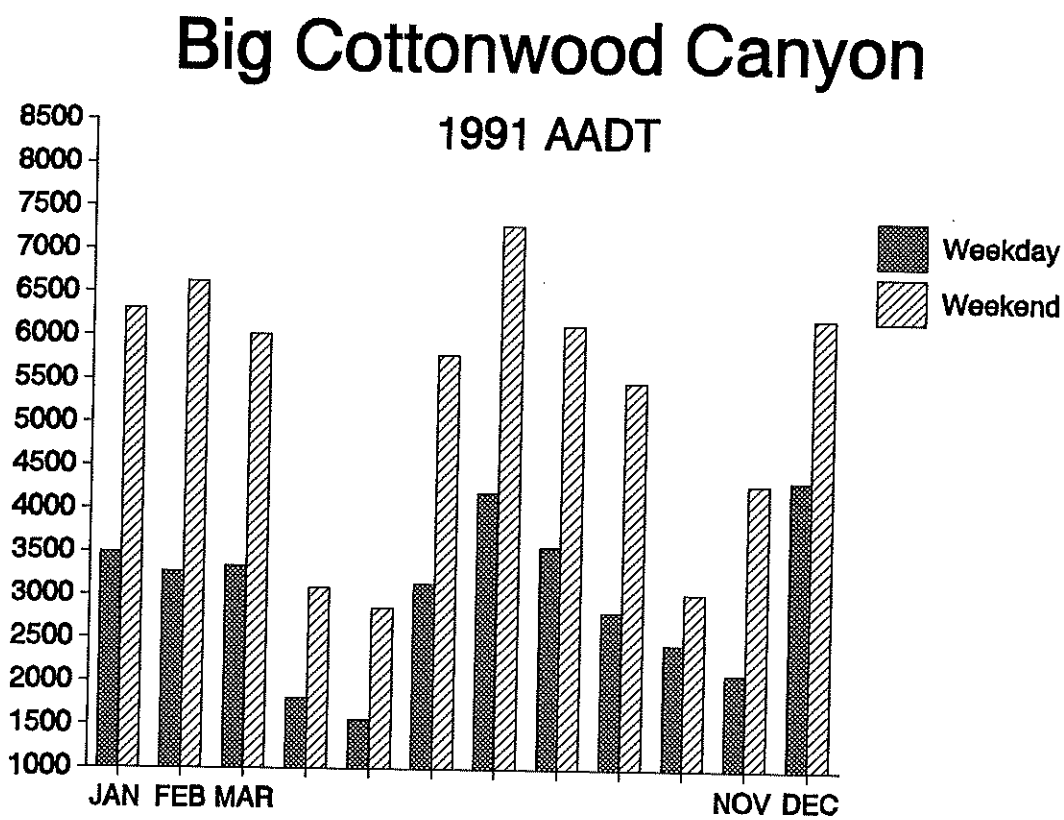

Figure 1. Traffic volume by month in Big Cottonwood Canyon

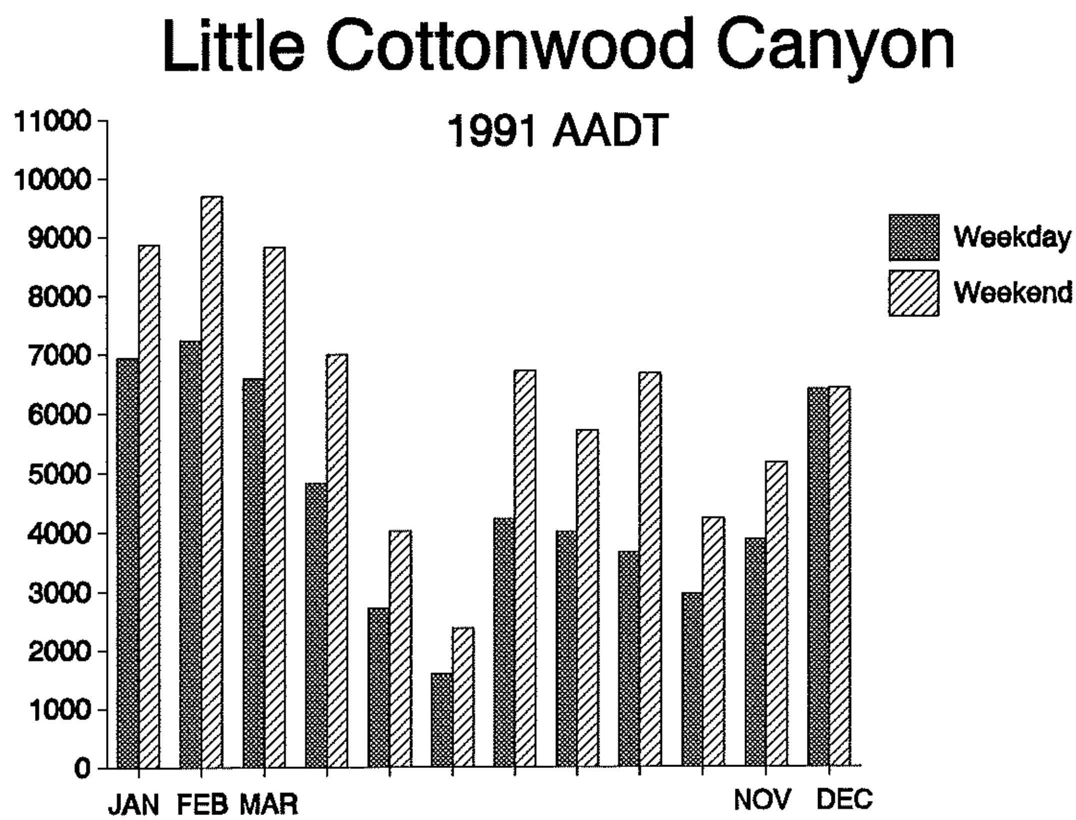

Figure 2. Traffic volume by month in Little Cottonwood Canyon

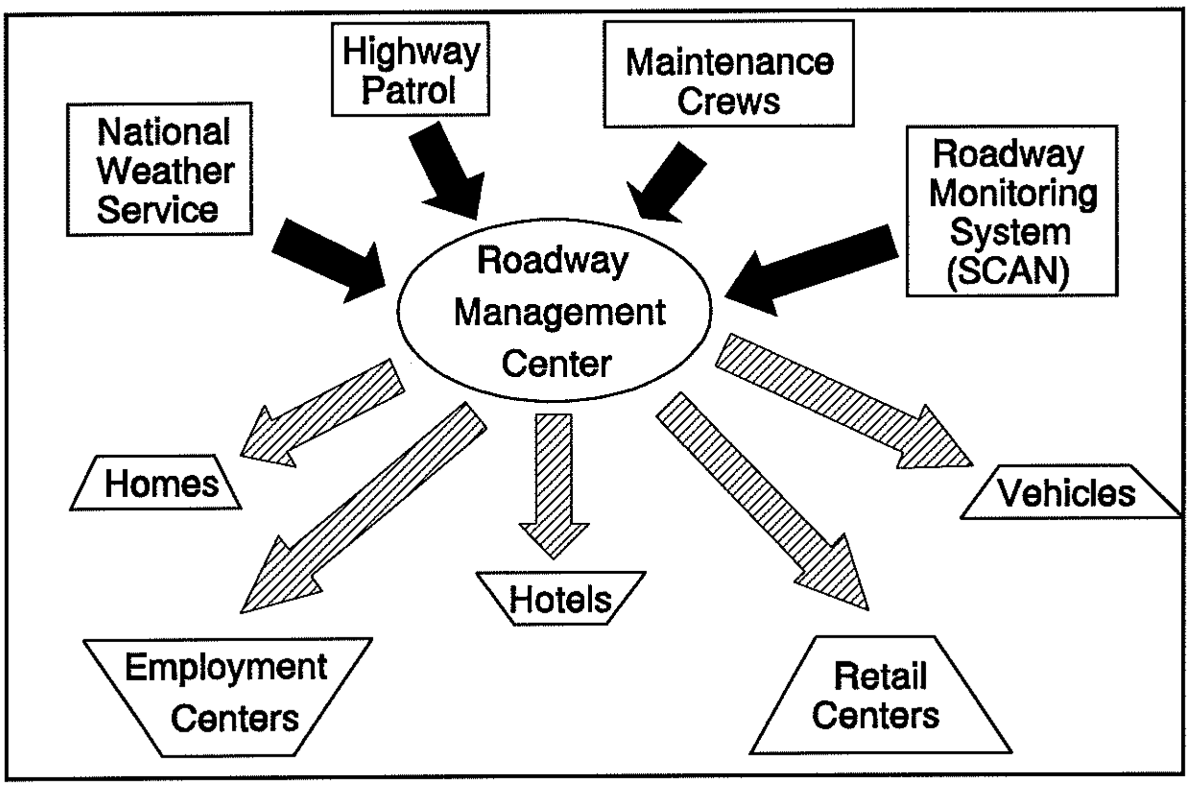

Figure 3. Prototype rural regional ATIS.

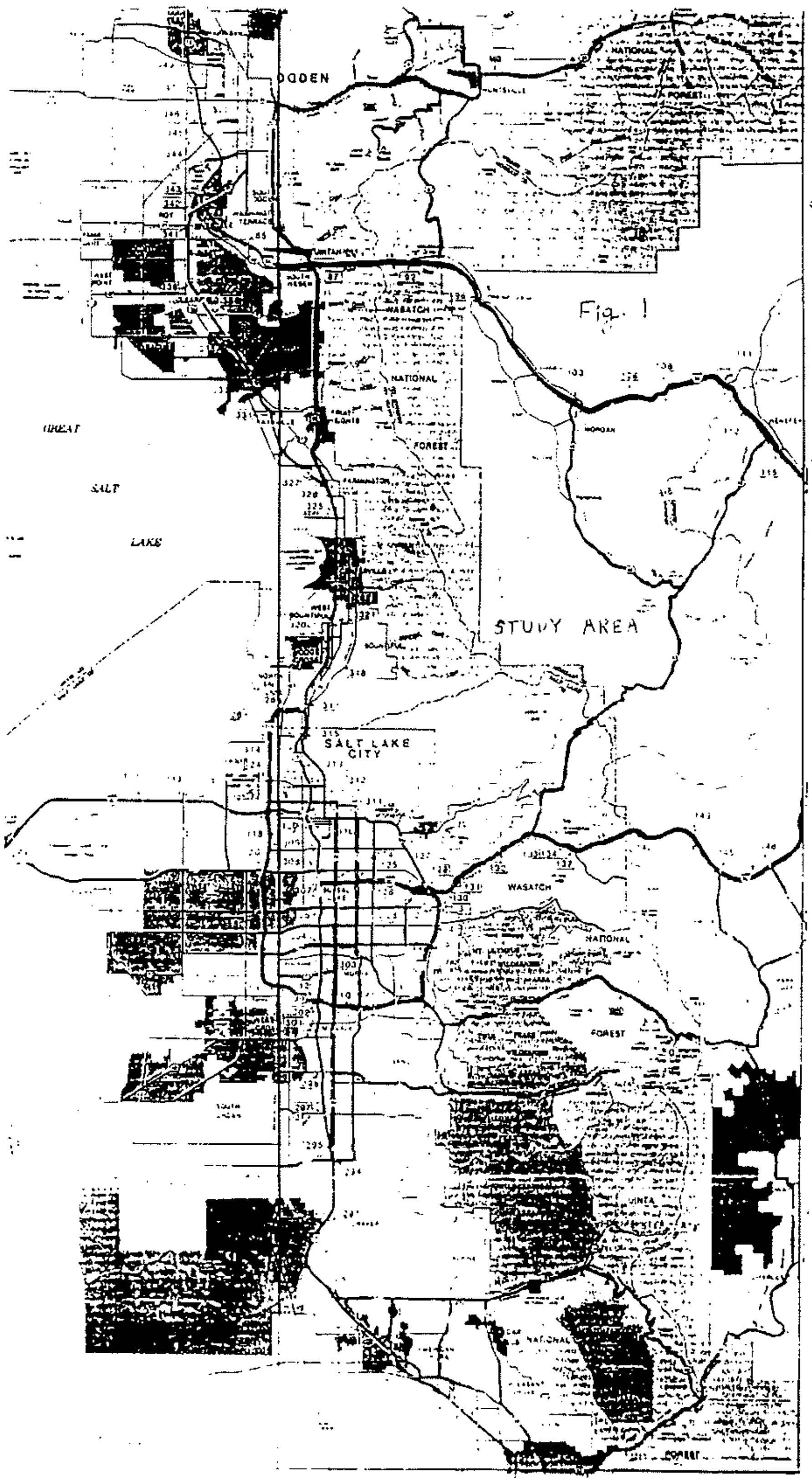

Figure 4. Map of study area

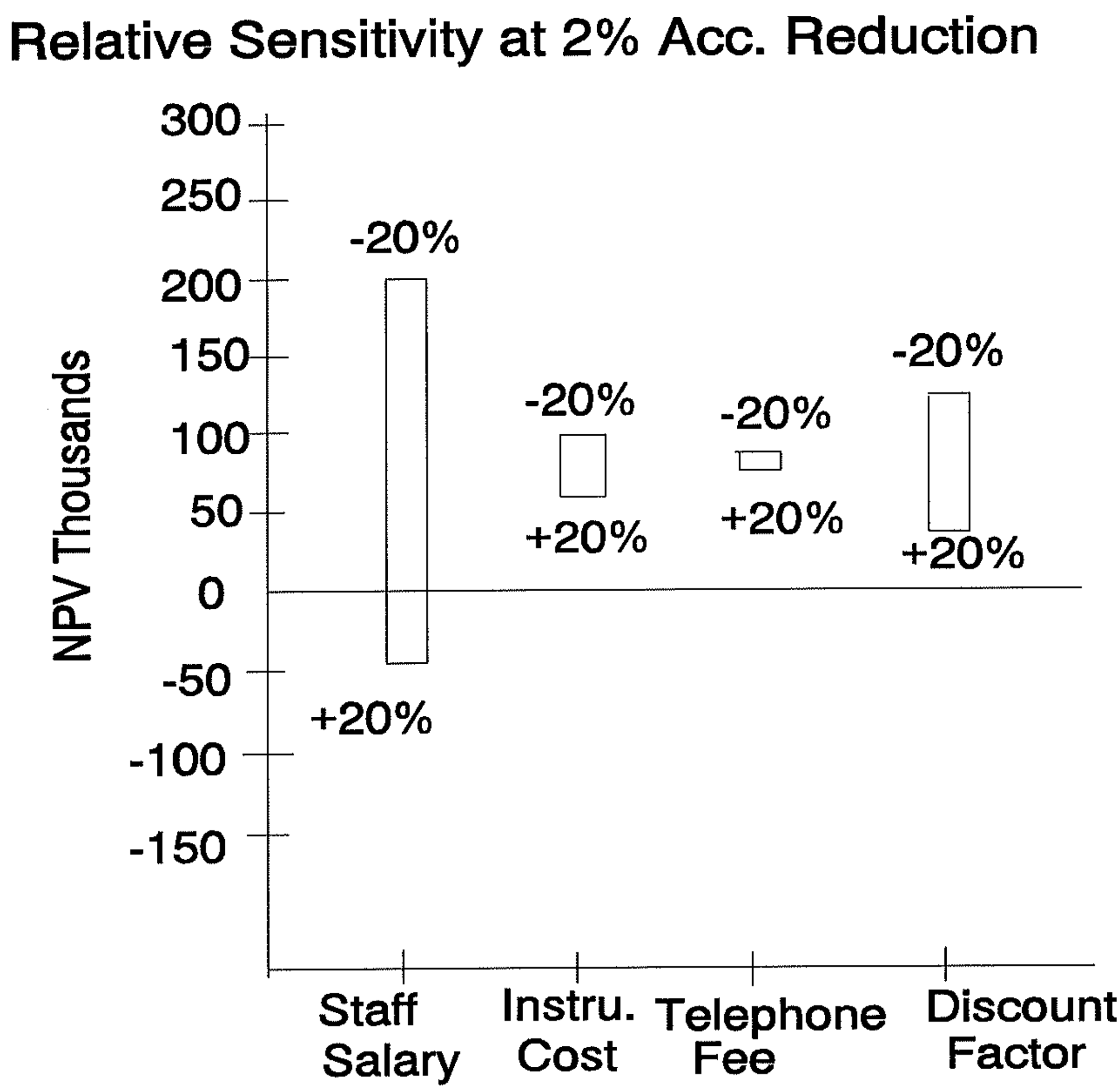

Figure 5. Sensitivity analysis: 2% accident reduction

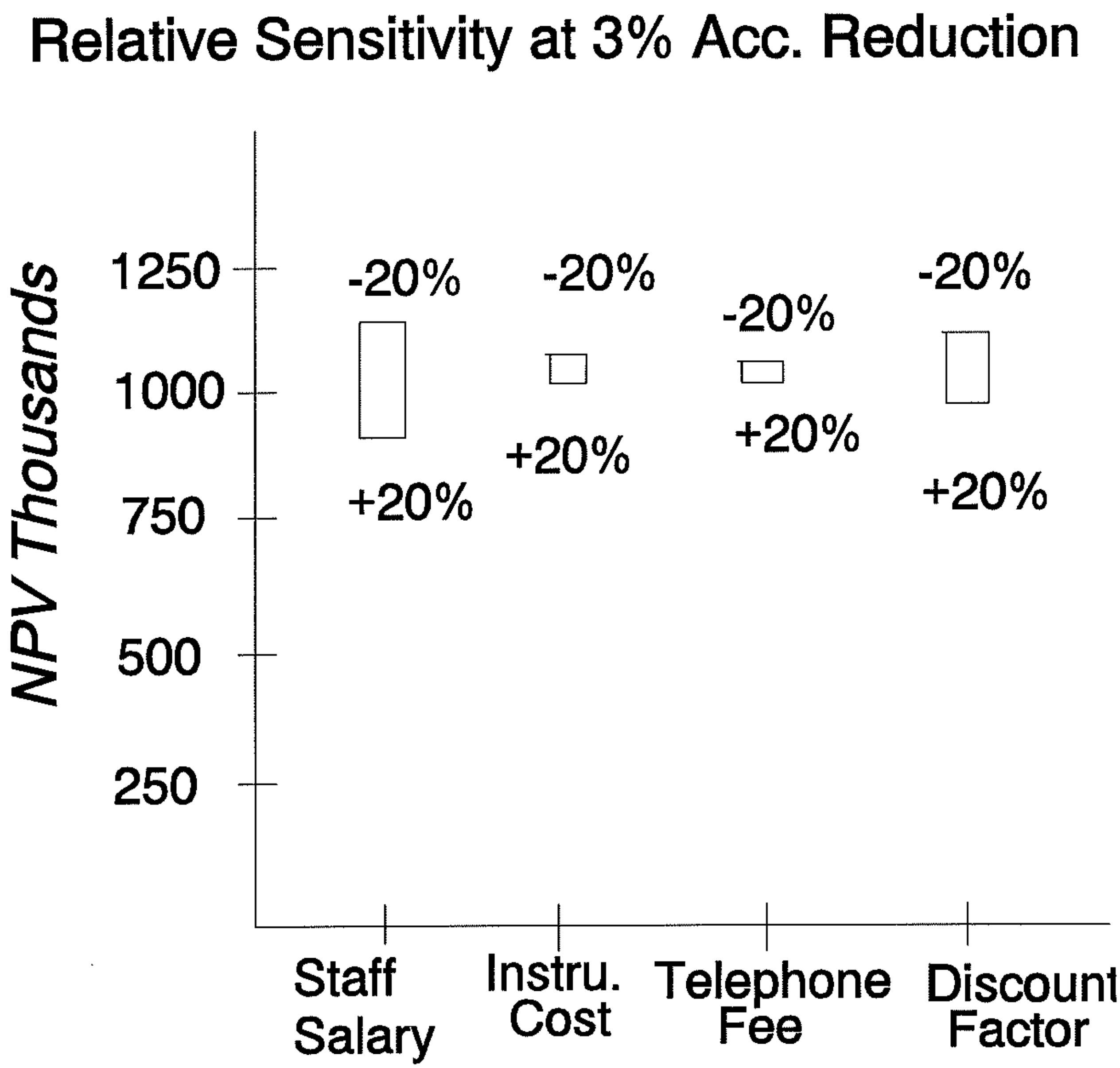

Figure 6. Sensitivity analysis: 3% accident reduction

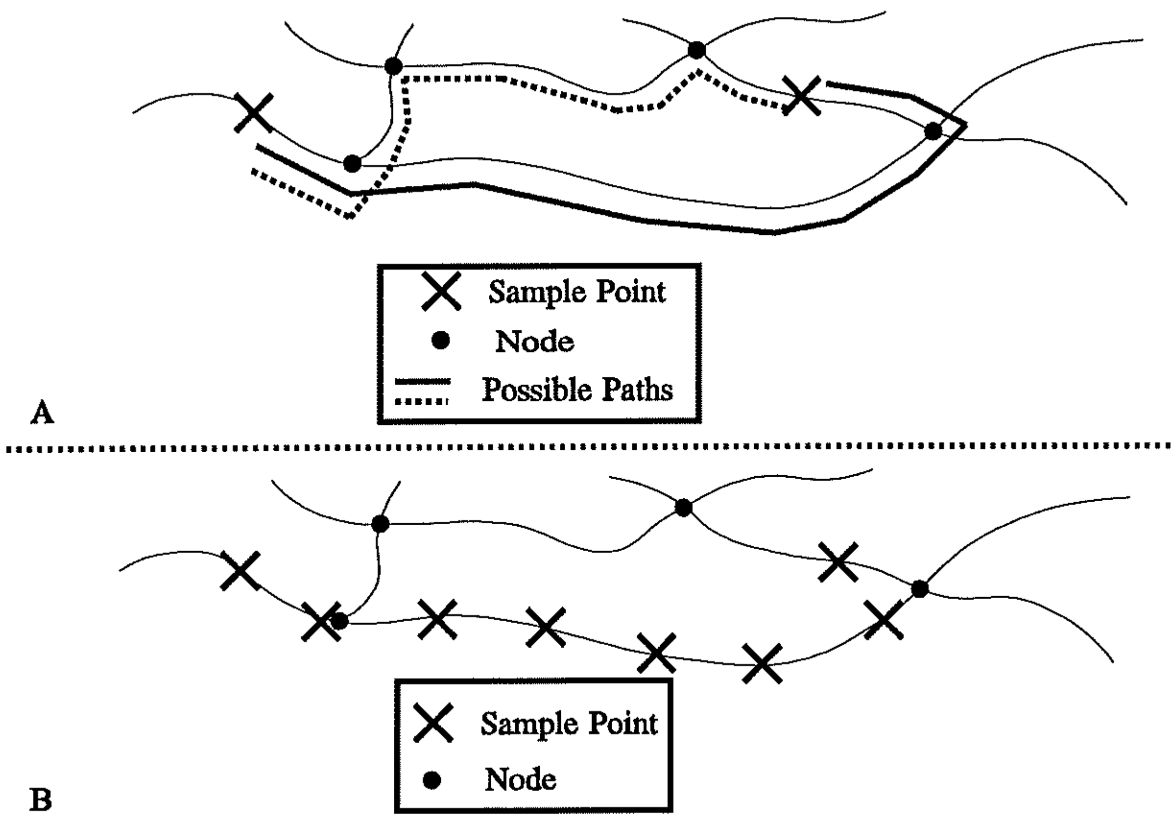

Figure 7. Examples of location sampling techniques

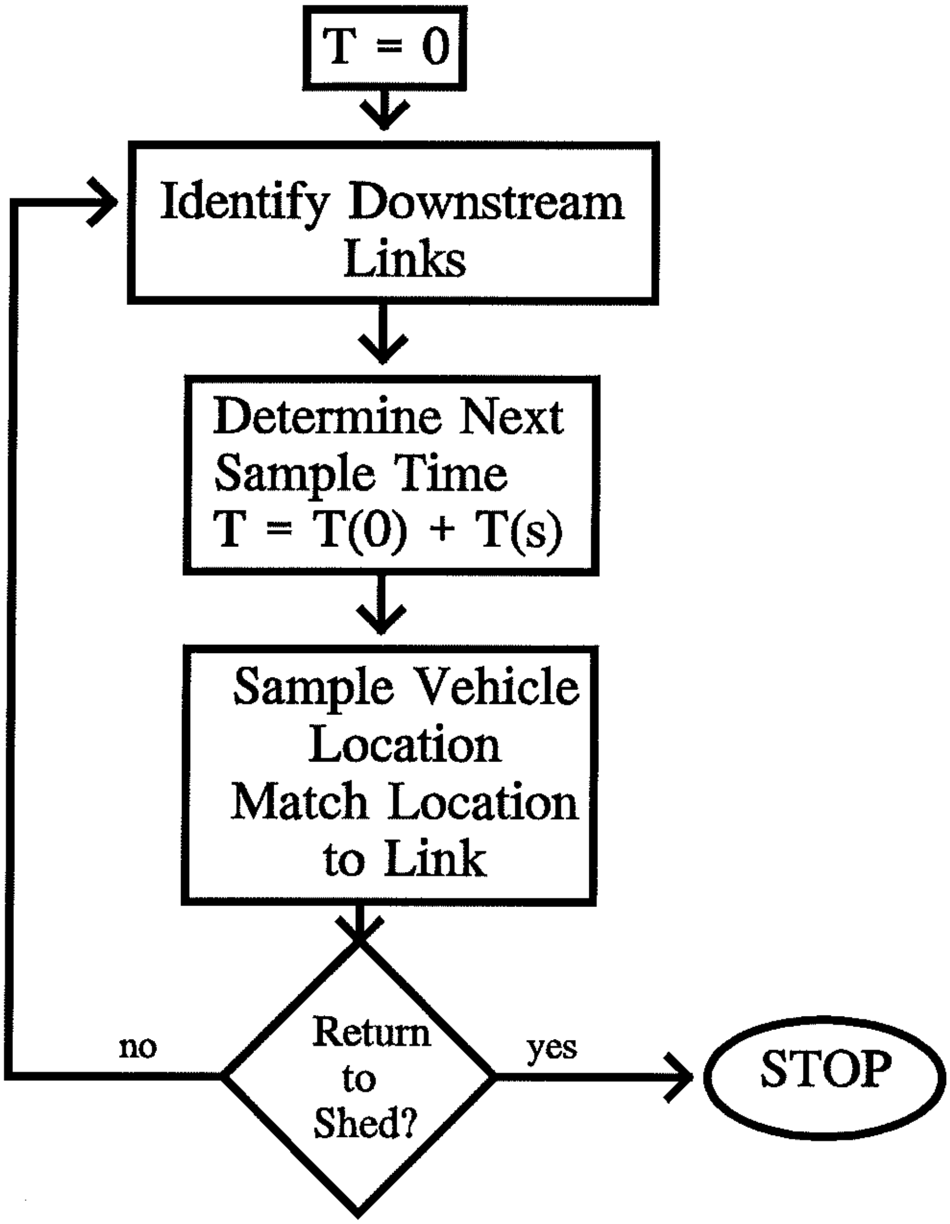

Figure 8. Flow chart for tracking algorithm

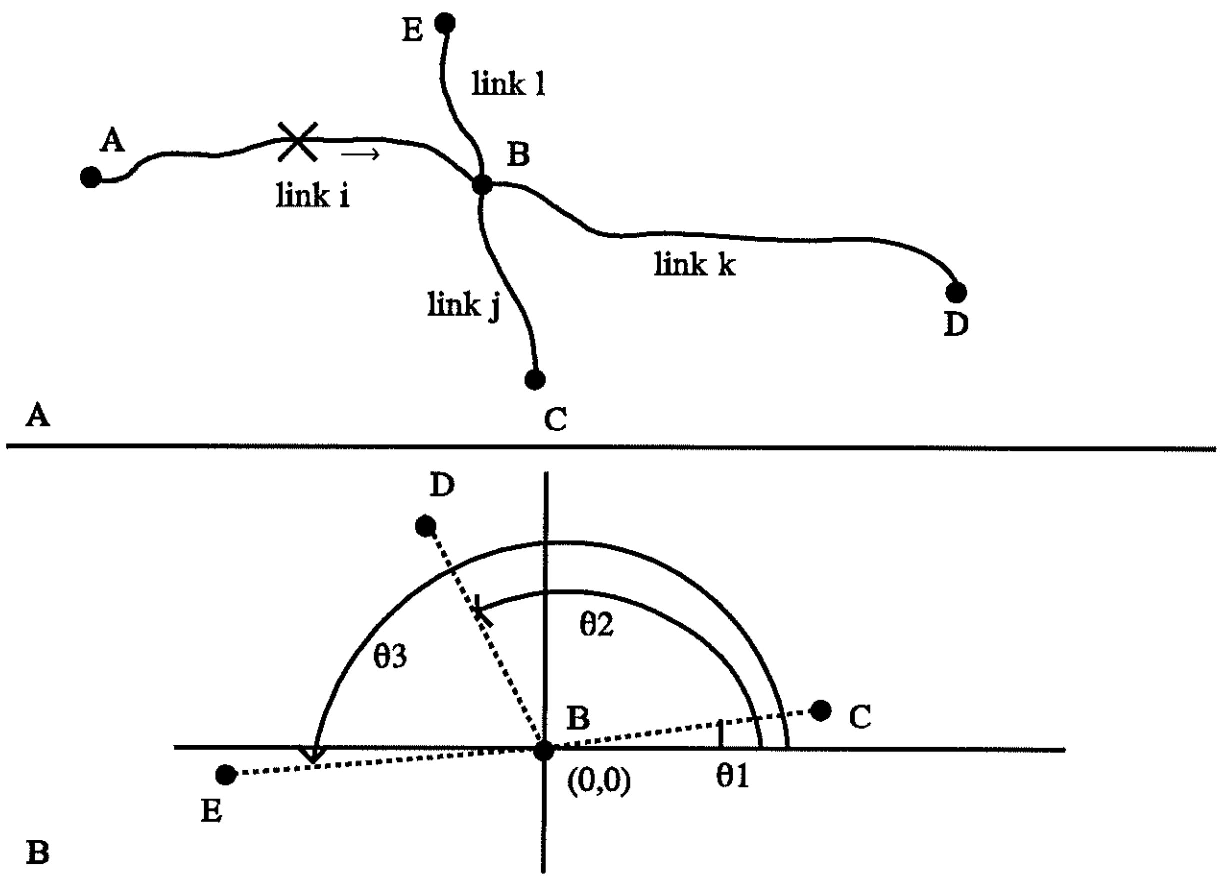

Figure 9. Downstream link candidates and determining turn penalties

APPENDICES

APPENDIX A

Literature Review

An evaluation of the Los Angeles Automated Traffic Surveillance and Control System concludes that stops are reduced by 35%, intersection delay by 20%, travel time by 13%, fuel consumption by 12.5% and air emissions by 10%. The benefit/cost ratio is 9.8:1 and the system paid for itself in less than one year (Rowe, 1991).

According to Stafford (1990), almost $750 billion in time resources are devoted to travel in the U.S. each year. Growing urbanization will increase this figure unless new approaches are deployed. Some preliminary work with IVHS systems indicates it is difficult but possible to achieve savings in the range of 10 percent. At a cost of $750 billion per year, this implies a potential savings of $75 billion per year.

A study conducted by Aerde and Blum (1988) shows that improvements on existing routes can be made through effective utilization of real-time traffic flow and incidents. The benefits of electronic route guidance are as follows:

(a) More drivers will be aware of shorter or less congested routes.
(b) Drivers will be aware of such routes only on a particular day or at a particular time.
(c) If only a small percentage of drivers participate in the route guidance, all other drivers will experience less congestion.

Hitchcock (1991) conducted a study in which relevant records for each accident were examined by professionals at the scene within half an hour of their occurrence, supplemented by interviews with participants in the accidents. He found that, with full implementation of the devices, vehicle accidents would be reduced approximately 25% under the following assumptions:

- All devices work as intended
- All drivers react as intended
- There are no side effects, particularly no behavioral changes.

Hitchcock (1992) reviews the effects of an AVCS device on road accidents and identifies six types of effects on accidents related to the evaluation of a device. These are:

1. Effect A: Reduction of accidents due to the intended operation of the device.
2. Effect B: Changes in driver behavior which counteract the saving effects of the device.
3. Effect C: Driver habituation, i.e. accidents generated in a non-equipped vehicle by a driver who has learned to rely on a device.
4. Effect D: Accidents due to faulty design or operation.
5. Effect E: Failure to react or respond to the device by the drivers.
6. Effect F: Benefit might only be for the safety-conscious drivers without the actual benefit of the device.

Each of these effects must be considered when evaluating IVHS devices in terms of safety. Hitchcock's paper focuses on effect A. Starting by examining the records of actual accidents, the investigator determines whether a device could have affected the course of each accident. This method of analysis is appropriate where "in-depth data bases" are available. In Hitchcock's application, "in-depth data" are data relevant to the driver's behavior during the accident. Collecting this type of data is very expensive so Hitchcock uses the NASS data (NHTSA's National Accident Sampling System) to evaluate seven types of devices. Without suitable interview data, there is a high degree of uncertainty with this type of approach.

Several studies show that accident rates during winter period is greater than the rest of the year. A study done by Frantzeskakis (1983) on two highway sections of the Greek National Road Network showed that accident rates are 38% higher in the period from November to March as compared to the rest of the year.

A research under the Strategic Highway Research Program (SHRP) in 1988 has shown that detailed information on weather and road condition during winter can not only reduce accidents, but also improve highway maintenance managers' ability for snow and ice control and provide greatest benefit-cost ratio (Boselly, 1992).

The need for information about current road and travel conditions during winter is of special concern in the mountain states. A study done by Piled and Wilson (1992) in Wyoming indicates that:

1. Motorists have consistent adverse winter travel information needs.
2. The Changeable Message Sign (CMS) is an important source of adverse winter travel information for rural interstate motorists.
3. Road surface condition is the primary information desired, with visibility secondary. When surface condition is poor, however, visibility information becomes more important.
4. Currently, the primary source of information for interstate truckers during adverse road and travel conditions is the CB radio.

Recently a new pavement weather monitoring system called SCAN (Surface Condition Analyzing) was developed by Surface Systems Inc. (SSI). A single unit includes up to 4 pavement sensors which can detect pavement conditions, pavement temperature, wet/dry status, chemical presence, etc. The sensors are wired to a Remote Processing Unit (RPU) at the side of the roadway. Air temperature, relative humidity, and wind speed and direction can also be measured by this system. Sensor information is stored in the RPU and is processed by a remote Central Processing Unit (CPU) at regular intervals. A continuous 24 hour weather forecast can be produced by SSI meteorologists projecting pavement and air temperature, wind speed and direction, and precipitation (Yamin, 1991). The main disadvantage of this system is that each RPU provides data for only 2500 ft. in each direction, amounting to less than a mile in both directions. Also, the RPU system is very expensive as it costs approximately $50,000 for each one mile section.

The number of accidents during winter needs special attention as it is a significant problem in mountain states. French and Wilson (1992) did a study on Interstate 80 between Laramie and Cheyenne, Wyoming, to determine trends in winter accidents. Accident data for the last five years at that site show 61% of the total yearly accidents occur during poor roadway conditions such as ice, snow, or slush. The average accident rate during poor road and travel conditions was 11.63 per million vehicle miles, 13 times greater than the accident rate during favorable road conditions. One possible solution given for addressing the winter-time accident problem is communication of current road and travel conditions. Their study evaluated real-time weather information provided by the remote weather information system (RWIS) which is similar to the SCAN system previously described. Measured weather data included presence of precipitation, surface pavement temperature, air temperature, relative humidity, and wind speed and direction. Road users and snow plow operators were also surveyed at the same time to determine their perceptions of road and travel conditions. It was found that the RWIS report did not correlate well with road conditions reported by road users and snow plow operators. Thus, unless the RWIS is further upgraded, it should not be used for roadway information.

Swift and Wheeler (1992) described a project conducted by the State Highway Administration (SHA) in Maryland during the winter of 1992 for snow removal activities. In their study, monitors traveled state routes during a snow-storm. Information concerning roadway conditions is communicated to traffic center via radio or telephone. Personnel in the center encode this data into a digital data base on an Intergraph work station. Roadway and weather information is sent to a backup computer and district maintenance offices. The following information is then available:

1. Graphic displays of travel conditions of state primary and interstate highways by system and county, and
2. Reports of special conditions and displays of incidents, conditions, or travel speed.

The primary disadvantage of this approach is that it requires personnel to act as roadway monitors, placing them in dangerous work situations.

According to Haselkorn (1992), the effectiveness of ATIS depends upon human willingness to change travel behavior. A study conducted in Seattle shows that 23% of all commuters are reluctant to change their trip irrespective of anything. Twenty one percent of travellers are willing to change their route before and during the commute. The third group (40%) is willing to change both route and time. If appropriate information is given, this group will adjust their departure time and route before and during travel. Another group identified in the study is exclusively pre-trip changers. They consist 16 percent of total commuters. Persons belonging to this group are very flexible prior to travelling, but once they start their trip, they are very unwilling to change their route.

From the above mentioned literature review, it is obvious that detailed information on roadway and weather conditions is necessary to improve mobility and decrease accidents. This information should include real time data for better and more effective impact. The study presented here includes information on real time roadway conditions which is displayed in graphic pictures at different hotels and information centers to help people understand current roadway conditions during winter.

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APPENDIX B

Supplementary Tables

Table 1. Number of PDO Accidents in different years for rural roads

S.R. #	1987	1988	1989	1990	1991
39	17	19	19	21	23
40	12	18	21	29	30
65	0	1	2	1	0
66	0	6	0	2	0
71 (part)	34	54	33	37	44
74	2	15	3	0	6
I-80 (part)	30	29	18	51	33
84	10	16	17	18	19
89 (part)	84	137	86	81	88
92	15	6	0	2	7
113	1	5	5	1	0
146	2	0	12	0	1
162	1	8	4	3	0
165	8	11	13	16	16
189 (part)	12	26	8	21	25
190	0	26	10	13	23
210	42	35	32	21	38
224	27	31	34	36	39
226	4	0	2	0	0
248	6	9	9	3	9
SUM	307.00	452.00	328.00	356.00	401.00

Table 2. Number of minor accidents in different years for rural roads

S.R. #	1987	1988	1989	1990	1991
39	0	0	4	4	7
40	1	1	0	4	0
65	0	0	0	0	0
66	0	0	0	0	0
71 (part)	11	20	0	7	16
74	0	1	0	0	1
I-80 (part)	6	3	2	2	5
84	0	13	0	0	3
89 (part)	17	25	25	22	21
92	2	0	0	2	7
113	0	0	0	0	0
146	0	0	0	0	2
162	0	0	0	0	0
165	0	9	3	3	0
189 (part)	4	0	1	1	3
190	0	2	3	4	7
210	3	3	5	4	6
224	3	3	3	5	6
226	0	0	0	0	0
248	0	3	0	2	0
SUM	47.00	83.00	46.00	60.00	84.00

Table 3. Number of medium accidents in various years for rural roads

S.R. #	1987	1988	1989	1990	1991
39	7	0	0	0	7
40	3	3	0	1	2
65	0	0	0	0	0
66	0	0	0	0	0
71 (part)	7	5	0	1	0
74	0	0	0	2	3
I-80 (part)	8	3	2	2	3
84	0	2	4	0	0
89 (part)	8	8	8	13	19
92	3	4	0	4	0
113	0	0	0	1	1
146	0	0	0	1	2
162	1	0	0	0	0
165	1	1	4	1	0
189 (part)	0	5	2	2	1
190	0	2	0	1	3
210	7	4	3	3	0
224	8	3	0	0	1
226	0	0	0	0	0
248	1	0	0	0	0
SUM	54.00	40.00	23.00	32.00	42.00

Table 4. Number of serious accidents in various years for rural roads

S.R. #	1987	1988	1989	1990	1991
39	0	2	3	2	3
40	1	7	2	2	0
65	0	0	0	0	0
66	0	0	0	0	0
71 (part)	0	4	0	2	0
74	0	0	0	0	3
I-80 (part)	9	2	4	8	7
84	0	0	1	1	2
89 (part)	5	4	4	9	13
1392	0	0	0	2	4
113	0	0	0	0	0
146	0	2	2	1	2
162	0	0	0	0	0
165	2	2	5	2	4
189 (part)	1	3	4	6	0
190	0	1	3	0	0
210	0	1	0	2	0
224	7	3	5	2	4
226	0	0	0	0	0
248	0	0	0	0	0
SUM	25.00	31.00	33.00	39.00	42.00

Table 5. Number of fatal accidents for different years for rural roads

S.R. #	1987	1988	1989	1990	1991
39	0	0	0	0	0
40	0	2	0	0	0
65	0	0	0	0	0
66	0	0	0	0	0
71 (part)	0	0	0	0	0
74	0	0	0	0	0
I-80 (part)	0	0	0	2	0
84	0	0	0	0	0
89 (part)	0	0	2	0	0
92	0	0	0	0	0
113	0	0	0	0	0
146	0	0	0	0	0
162	0	0	0	0	0
165	0	0	0	0	0
189 (part)	0	0	0	1	0
190	0	0	0	0	0
210	0	0	0	0	0
224	0	0	0	0	0
226	0	0	0	0	0
248	0	0	0	0	0
SUM	0.00	2.00	2.00	3.00	0.00

Table 6. Number of property damage only accidents in urban roads for different years

S.R. #	1987	1988	1989	1990	1991
52	5	10	19	25	26
71 (part)	13	73	37	51	26
I-80 (part)	65	103	109	81	95
89 (part)	22	109	72	50	56
171	65	123	52	63	79
181	12	46	36	30	39
189 (part)	10	51	8	25	25
195	2	8	9	9	11
203	6	47	25	26	31
209	26	52	37	27	30
215	73	197	122	142	173
266	37	41	25	42	31
SUM	336.00	860.00	551.00	571.00	622.00

Table 7. Number of minor accidents in urban roads for different years

S.R. #	1987	1988	1989	1990	1991
52	1	0	3	2	4
71 (part)	11	2	7	9	9
I-80 (part)	3	10	13	10	15
89 (part)	11	16	18	21	25
171	14	22	30	16	30
181	0	0	8	8	11
189 (part)	0	8	7	4	8
195	0	1	0	0	0
203	10	5	4	8	9
209	0	13	7	6	2
215	27	34	31	46	42
266	9	7	2	7	3
SUM	86.00	118.00	130.00	137.00	158.00

Table 8. Number of medium accidents in urban roads for different years

S.R. #	1987	1988	1989	1990	1991
52	0	0	0	2	0
71 (part)	5	5	4	5	6
I-80 (part)	0	4	5	10	12
89 (part)	1	4	3	7	8
171	8	12	13	10	14
181	1	4	0	0	0
189 (part)	0	0	5	4	0
195	0	0	0	1	0
203	2	0	4	4	0
209	7	8	2	2	10
215	3	16	18	24	27
266	4	2	6	7	11
SUM	31.00	55.00	60.00	76.00	88.00

Table 9. Number of serious accidents in urban roads for different years

S.R. #	1987	1988	1989	1990	1991
52	0	7	0	0	3
71 (part)	0	3	6	2	0
I-80 (part)	2	1	4	5	13
89 (part)	2	0	7	0	1
171	2	5	4	9	2
181	0	4	0	0	2
189 (part)	0	7	8	2	2
195	0	0	0	0	0
203	2	0	4	0	5
209	2	3	3	5	6
215	3	26	6	15	20
266	0	8	4	0	0
SUM	13.00	64.00	46.00	38.00	54.00

Table 10. Number of fatal accidents in urban roads for different years

S.R. #	1987	1988	1989	1990	1991
52	0	0	0	0	1
71 (part)	0	0	0	0	0
I-80 (part)	0	0	0	0	0
89 (part)	0	0	0	0	0
171	0	0	0	0	0
181	0	1	0	0	0
189 (part)	0	0	0	0	2
195	0	0	0	0	0
203	0	0	0	0	0
209	0	0	0	0	0
215	0	2	1	0	3
266	0	0	0	0	0
SUM	0.00	3.00	1.00	0.00	6.00