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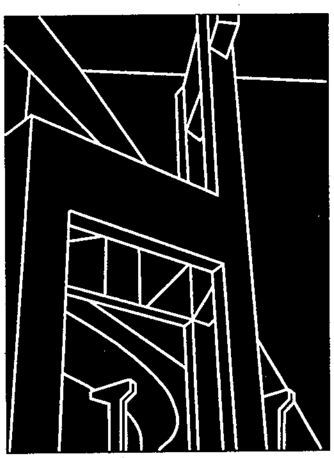
ROAD WEATHER INFORMATION SYSTEM DECISION SUPPORT TOOL

Carl Haas, José Weissmann, Benjamin McKeever, and Richard Greer



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16. Abstract

In order to ensure safer driving conditions on highways, state highway agencies are exploring the use of new technologies, called road weather information systems (RWIS), that will improve the flow of information regarding hazardous road conditions. The objective of this report is to provide a systematic methodology for highway agencies seeking the costs and benefits associated with implementing RWISs. This objective was achieved through the development of an RWIS Decision Support Tool. This analysis tool provides highway agency decision makers with a methodology through which different RWIS implementation alternatives can be evaluated from economic, qualitative, and environmental perspectives. The RWIS Decision Support Tool also includes an RWIS project prioritization model that ranks various RWIS projects by need to help determine and document which potential sites are the most crucial.

In addition, this report includes two case studies demonstrating the use of the RWIS Decision Support Tool. The first case study evaluated various alternatives for implementing a low water crossing monitoring system (LWCMS) in Kerrville, Texas. Using the results obtained from the model, we determined that the best solution would be to implement an LWCMS on FM 1338 at Goat Creek crossing. The purpose of the second case study was to evaluate whether it is cost beneficial to implement an RWIS on Interstate 20 near Abilene, Texas. The model determined that it was cost beneficial to implement this system. This report concludes with an RWIS implementation plan for the Texas Department of Transportation and provides recommendations for future research involving road weather information systems.

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ROAD WEATHER INFORMATION SYSTEM DECISION SUPPORT TOOL

by

Carl Haas

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Research Report Number 1380-3F

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Develop a Remote Automatic Monitoring and Public Information System for Hazardous Conditions

Conducted for the

TEXAS DEPARTMENT OF TRANSPORTATION

in cooperation with the

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by the

CENTER FOR TRANSPORTATION RESEARCH

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IMPLEMENTATION STATEMENT

This report presents a road weather information systems (RWIS) Decision Support Tool for highway agency decision makers. This analysis tool may be implemented to provide the following:

1. a methodology through which different RWIS implementation alternatives can be evaluated from economic, qualitative, and environmental perspectives; and
2. an RWIS project prioritization model that will rank various RWIS projects by need to help determine and document which potential sites are the most crucial.

Overall, the project findings reported in this document will be beneficial to highway agency decision makers that are considering implementing an RWIS.

ABSTRACT

To ensure safer driving conditions on highways, state highway agencies are exploring the use of new technologies that can improve the flow of information regarding hazardous road conditions. One such technology — termed *road weather information systems* (RWIS) — is the subject of this report. Our primary objective was to provide a systematic methodology that could be used by highway agencies seeking to identify the costs and benefits associated with implementing an RWIS. This objective was achieved through the development of what we term an RWIS "Decision Support Tool." This analysis tool provides highway agency decision makers with a methodology through which different RWIS implementation alternatives can be evaluated from economic, qualitative, and environmental perspectives. The RWIS Decision Support Tool also includes an RWIS project prioritization model that ranks various RWIS projects by need to help determine and document which potential sites have the most critical need.

In addition, this report includes two case studies demonstrating the use of the RWIS Decision Support Tool. The first case study evaluated various alternatives for implementing a low water crossing monitoring system (LWCMS) in Kerrville, Texas. From the results obtained by the model, it was determined that the best solution would be to implement an LWCMS on FM 1338 at Goat Creek crossing. The purpose of the second case study was to evaluate whether it is cost beneficial to implement an RWIS on Interstate 20 near Abilene, Texas. The model determined that it was indeed cost beneficial to implement this system. The report concludes with an RWIS implementation plan for the Texas Department of Transportation; recommendations for future research involving road weather information systems are also provided.

the Texas Department of Transportation. This report does not constitute a standard, specification, or regulation.

There was no invention or discovery conceived or first actually reduced to practice in the course of or under this contract, including any art, method, process, machine, manufacture, design or composition of matter, or any new and useful improvement thereof, or any variety of plant, which is or may be patentable under the patent laws of the United States of America or any foreign country.

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BIDDING, OR PERMIT PURPOSES

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Research performed in cooperation with the Texas Department of Transportation and the U.S. Department of Transportation, Federal Highway Administration.

TABLE OF CONTENTS

CHAPTER 1. INTRODUCTION

1.1 BACKGROUND

Highway agencies have a public mandate to use labor, equipment, and materials as cost effectively as possible. Accordingly, the sometimes substantial costs associated with the maintenance of rural roads during periods of inclement weather are a major concern. Increasing litigation has also concerned highway agencies, which may be liable for accidents attributable to a deficiency in design or operations [Eck 1983]. Low-volume roads, typically constructed to standards lower than those associated with high-volume routes, appear particularly susceptible to lawsuits. Also, funding levels are not always sufficient to ensure the adequate maintenance of problem areas during bad-weather conditions. This is especially a problem with icing on bridge decks and flooding at low water crossings.

In order to ensure safer driving conditions on rural highways, state highway agencies are exploring the use of new technologies that can improve the flow of information about road conditions. Several states within the U.S. and many countries in Europe have established networks of data-gathering systems that provide valuable information to decision makers and the traveling public regarding potentially hazardous road conditions [Boselly 1993]. These systems are often referred to as *road weather information systems* (RWIS).

An RWIS allows highway agencies to better manage their resources during weather emergencies by providing maintenance personnel with real-time information about low water crossing conditions and bridge deck icing within their area of responsibility. The availability of this information can reduce the number of trips made by maintenance crews assigned to check on remote sites. Also, by providing accurate forecasts of weather and pavement conditions, an RWIS can allow maintenance crews to pretreat roads before a winter storm hits. This pretreating process, known as anti-icing, requires only a fraction of the materials, equipment, and labor needed to de-ice roads after a winter storm hits. Finally, RWIS information can be used during periods of good weather as well, by assisting in the planning of those construction activities that depend on favorable weather and pavement temperatures.

By providing pretrip and enroute road condition information to drivers, an RWIS can reduce the risk of liability and can provide safer roads for highway agencies. Safer roads result in fewer accidents and, hence, fewer fatalities. Recent advances in remote sensing and telecommunications, together with the steep decline in their associated costs, have made RWIS implementation an entirely feasible and attractive solution to the problem of hazardous weather conditions on rural roads. Thus, an RWIS, in conjunction with Intelligent Transportation System (ITS) projects around the country, can enhance traveler safety and can reduce road maintenance expenditures.

1.2 PURPOSE

The purpose of this report is to describe a decision tool that will support the implementation of an RWIS. In this report, the term *road weather information system* is used to describe both low water crossing monitoring systems and bridge ice detection systems. The RWIS Decision Support Tool will help to quantify the costs and benefits associated with implementing an RWIS. This information will better allow highway agency decision makers to justify their RWIS implementation decisions. In addition, the RWIS Decision Support Tool includes an RWIS project prioritization model that can rank various RWIS projects based on need. Such a ranking exercise can help determine and document which potential sites are the most crucial.

1.3 SCOPE

The RWIS Decision Support Tool operates both at the network level and at the project level. At the network level, it provides key information to policy makers, planners, and decision makers on RWIS budgeting and planning. This information is helpful in decisions regarding resource allocation and project prioritization. At the project level, the RWIS Decision Support Tool can be used for specific projects to analyze alternatives, such as whether to implement an RWIS at a specific site.

1.4 ORGANIZATION

Chapter 2 of this report reviews current literature on road weather information systems and their economics. Chapter 3 discusses the key inputs that are involved in the implementation of the RWIS Decision Support Tool. These inputs include a listing of potential sites, site characteristics, site history, proximity to other sites, and budgetary constraints. Chapter 4 presents an RWIS life-cycle cost analysis; also included are a methodology for estimating RWIS costs and benefits, a model for calculating the net present worth of an RWIS, a project prioritization model, and guidelines for how to apply the tool. Chapter 5 and Chapter 6 describe applications of the RWIS Decision Support tool using Kerrville and Abilene, respectively, as case studies. Finally, Chapter 7 provides conclusions and makes recommendations for future research.

CHAPTER 2. BACKGROUND AND LITERATURE REVIEW

This chapter describes the major components of an RWIS and how they are integrated for two applications: (1) bridge ice detection systems, and (2) low water crossing monitoring systems. It also identifies a number of vendors that can provide a turnkey RWIS. Finally, this chapter presents a literature review of RWIS economics.

2.1 RWIS COMPONENTS

Road weather information systems sense and collect on-site weather and road condition information, process and disseminate the information, and create forecasts of road and weather conditions [Boselly 1993]. There are several components of an RWIS. These include:

- sensors,
- remote processing units (RPU),
- central processing units (CPU),
- telecommunications equipment to transmit data,
- computer workstations equipped with software, and
- forecasts from the National Weather Service or other meteorological services.

2.1.1 Sensors

The sensors include ice detection sensors, which are typically embedded in the pavement, and water level sensors, which tend to be installed in or around a creek bed. Most RWIS installations also include a number of atmospheric sensors that provide additional information about current weather conditions, such as air temperature, relative humidity, wind direction and speed, visibility, and presence of precipitation.

2.1.2 Remote Processing Units

Located at the site, RPUs are responsible for processing raw data from the sensors. These data, whether they are in digital or analog format, are converted to a usable form and then transmitted either to roadside message signs, to flashing lights, or to a CPU. The RPUs are usually either battery or solar powered.

2.1.3 Central Processing Units

CPUs are located at a central control office. The CPU analyzes, stores, and arranges the data from the RPUs. Data are received from the RPUs, usually via radio or telephone, and converted by the CPU into usable information and graphic displays for decision makers or meteorologists. In some cases, data are formatted for use in forecasting models.

2.1.4 Communications Equipment

Communications equipment used to transmit RWIS information comes in a variety of forms. Communications can be via direct wire connection, telephone, cellular link, radio, microwave, satellite, forecasts, or LAN. Direct connection requires only cable. For telephone communications, telephone lines and modems are needed. For radio links, transmitters/receivers, antennas, and sometimes repeaters are necessary. Microwave and satellite communications are slightly more expensive and require special types of transmitters/receivers and antennas. LAN connections require an Ethernet card, Token Ring, or some other type of networking device.

2.1.5 Computer Workstations

Computer workstations equipped with special software can be used to access the RWIS data stored on the CPU and to present the data to users in a variety of usable forms. These forms include tabulated text formats, Geographical Information Systems (GIS), map locators, voice messages, and graphical outputs. The displays can be tailored to the customer's needs.

2.1.6 Forecasts

The final components of an RWIS are weather and pavement forecasts. Forecasts are often considered separate from the other RWIS components because they require information from other sources. Typical sources of weather forecasts include the public media, the National Weather Service (NWS), and Value Added Meteorological Services (VAMS). Most public forecasts are issued by the NWS and retransmitted by broadcast media. According to many maintenance engineers, public forecasts are often too conservative and rarely provide adequate detail relating to specific sites. Highway decision makers must have accurate weather forecasts for specific sites in order to optimize their maintenance procedures. VAMS use NWS data and forecasts, specialized observations, and meteorological models to provide state agencies with specific weather packages tailored to meet an agency's needs. These packages usually include live radar observations and satellite images.

VAMS can also provide 24-hour pavement forecasts for each RWIS site being monitored. Pavement forecasts, used with bridge ice detection systems, graphically depict current and future pavement temperatures and conditions. These pavement forecasts can forewarn decision makers of potential problems so that they can act proactively rather than reactively. Such advanced warnings have saved state agencies money through reduced labor, materials, and equipment costs.

Another source of weather forecasts that has been gaining currency in recent years is the World Wide Web (WWW). Many NWS and public media weather forecasts are now available on the Web. Also, a number of news and weather centers are now adding live Doppler radar and satellite images to their Web sites. Figures 2.1 and 2.2 show the major components of a bridge ice detection system and a low water crossing monitoring system, respectively.

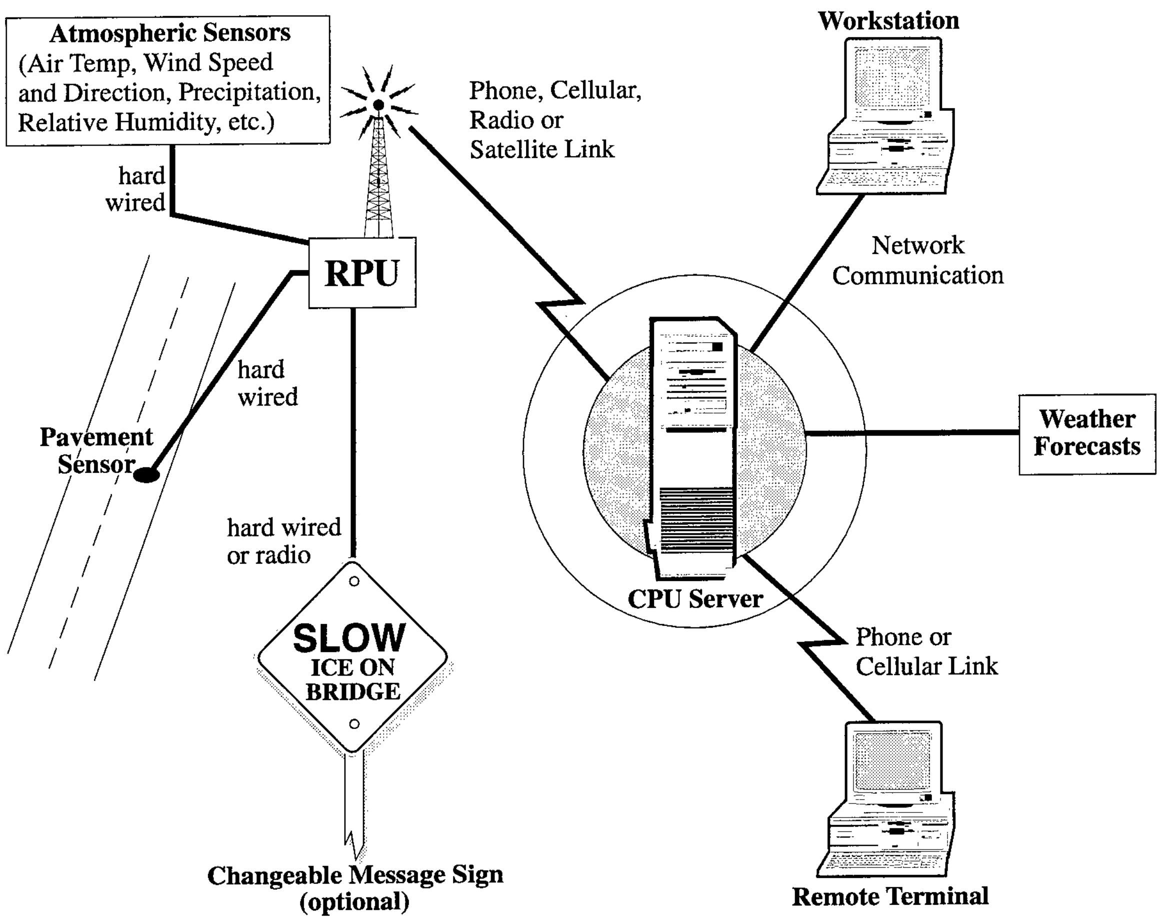

Figure 2.1 Major components of a bridge ice detection system

2.2 INVENTORY OF TURNKEY SYSTEMS

A number of vendors provide a turnkey RWIS for both bridge ice detection and low water crossing monitoring applications. The two main providers of bridge ice detection systems are Surface Systems, Inc. (SSI) and Vaisala, Inc. The SSI system (SCAN) has been widely used throughout the U.S. for the past ten years. Vaisala's system (ICECAST) has been used mostly in Europe, although there are a few ICECAST installations in Texas and in Minnesota. In recent years, smaller vendors have also begun to provide bridge ice detection systems. These vendors include Climatronics, Aanderraa, Coastal Environmental, and Reed Systems, Ltd. The cost of a typical RWIS for ice detection ranges from about \$10,000 to \$40,000 per site, depending on the complexity of the system and on the mode of communication.

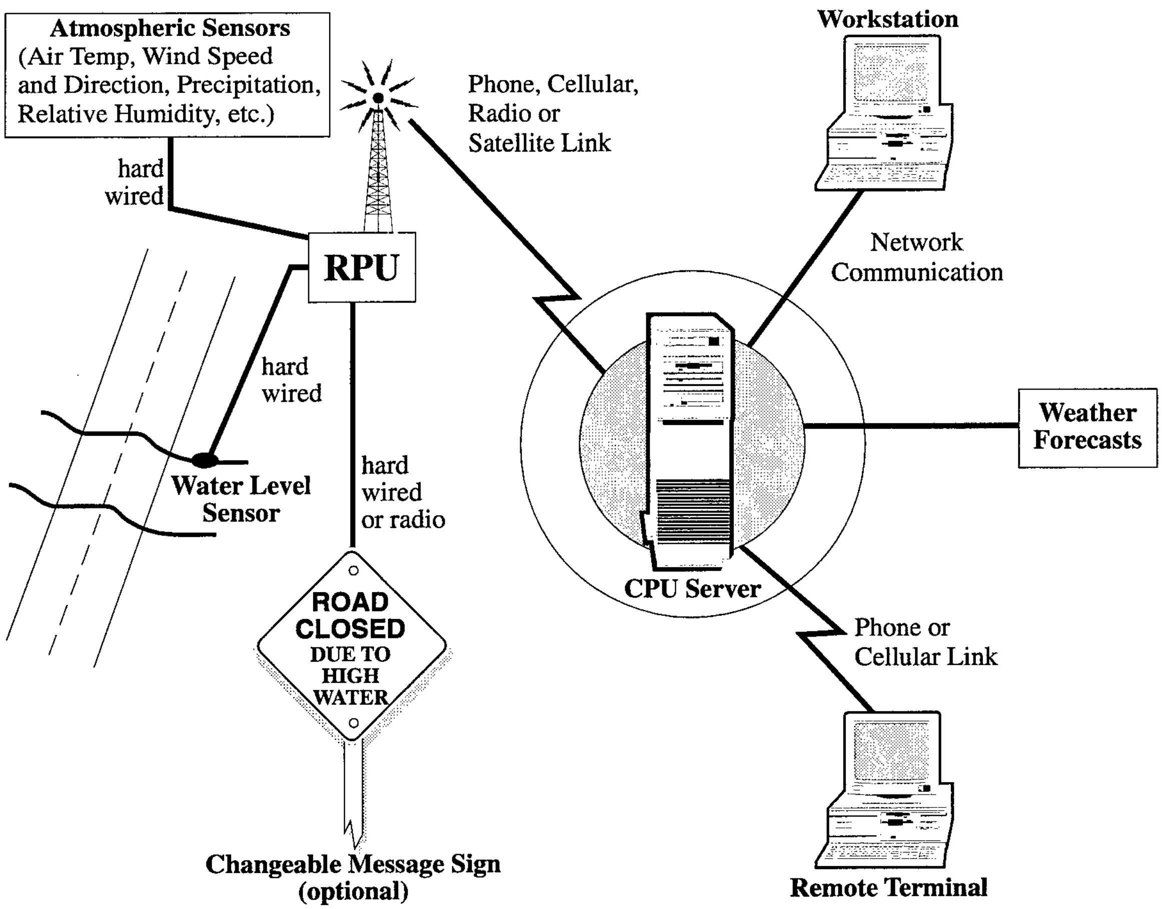

Figure 2.2 Major components of a low water crossing monitoring system

There are also a number of vendors that provide turnkey low water crossing monitoring systems (LWCMS). Remote Operating Systems (ROS), which operates out of San Antonio, has installations throughout Texas (e.g., in San Antonio, Kerr County, and in Lubbock). ATEK, another vendor of LWCMS equipment, has a system installed at a site just outside of Austin; so far the system appears to be working well. There is also a system called the Automatic Inundation Monitor (AIM) provided by Applied Sciences, Ltd. out of Des Moines, Iowa. AIM is a microprocessor-based flash flood alarm system, which may be used to actuate gates, lights, or telemetry. The cost of a typical LWCMS ranges from $5,000 to $20,000 per site, depending on complexity and mode of communication.

2.3 LITERATURE REVIEW OF RWIS ECONOMICS

The following section reviews the literature of various RWIS economic analyses conducted throughout the U.S. and Europe.

2.3.1 SHRP Research

In 1988, the Strategic Highway Research Program (SHRP) of the National Research Council initiated a project to evaluate the effectiveness of RWIS in reducing the costs of highway snow and ice removal. The investigation included a cost-benefit analysis of implementing road technologies. A 1992 article describes the statistical model used by SHRP to perform the cost-benefit assessment [Boselly 1992]. Model results show that the use of an RWIS can be cost effective if used proactively and in conjunction with accurate pavement and weather forecasts.

The model takes into account indirect and direct benefits and direct costs. Indirect benefits include improved traffic flow, reduced fuel consumption, reduced accident rates, and reduced insurance premiums. Direct benefits include reduced expenditures for labor, equipment, and materials. Direct costs were acquired from records of expenditures for snow and ice control.

In early 1991, SHRP also funded a multiyear study entitled "Development of Anti-Icing Technology" under project H-208 [SHRP 1994]. The objectives were to develop a better understanding of the conditions under which anti-icing could be effective, and to evaluate various anti-icing techniques that will have the greatest potential for success over a range of conditions. For this study, nine state highway agencies conducted anti-icing experiments when possible during the 1991-1992 and 1992-1993 winters.

As part of this study, a limited cost-benefit analysis was performed, one that considered such factors as accidents, materials, equipment, and labor costs. Estimates of accident rates under dry, wet, and icy pavement conditions were determined from accident, weather, and traffic volume data for selected sites in New York. The required material, equipment, and labor costs and the estimated effectiveness for anti-icing operations were based on the experience of participating states. These data were then combined in a cost-benefit analysis of pretreatment strategies. The results indicate that under certain conditions, anti-icing operations can reduce both public expenditures and accidents.

2.3.2 Wyoming Research

A 1993 Wyoming Transportation Department report described the potential for reducing accidents by using an RWIS to communicate current road and travel conditions to motorists [French and Wilson 1993]. According to that report, this information can be communicated to road users using a variety of devices, including changeable message signs, road and travel telephone numbers, road and travel information on public radio, and linear radio systems.

As part of the Wyoming study, an RWIS was installed for a 66-km (41-mile) section of Interstate 80 between Laramie and Cheyenne in southeast Wyoming. To evaluate the RWIS, an investigation of accident data was undertaken to determine whether certain user groups needed to be targeted for dissemination of RWIS information. An analysis of the accident data showed that the average accident rate during icy or snowy conditions was 13 times greater than the accident rate during favorable conditions. The study also found that poor pavement and visibility conditions had the greatest effect on average vehicle speeds during inclement conditions. Finally, the study concluded that the presently designed RWIS is limited in its ability to provide accurate information concerning adverse road conditions.

2.3.3 Wisconsin Research

A 1994 study undertaken in Milwaukee, Wisconsin, evaluated the effectiveness of winter road maintenance operations and their economic impact on road users [Hanbali 1994]. In addition to a cost-benefit analysis of winter road maintenance operations during snow and icy conditions, the study's report shows cost savings per vehicle kilometer of travel.

The road-user savings considered in the analysis included accident reduction, reductions in vehicle operating cost, and reduced travel time. It found that the majority of the savings were in accident reduction, and that winter road maintenance operations could reduce traffic accident costs during inclement conditions by as much as 88 percent and traffic accident severity by 10 percent. The research also found that during the first four hours of operations, the benefit-to-cost ratio of winter maintenance operations was 6.5:1.

2.3.4 Finnish Research

The Finnish National Road Administration has been studying weather and road surface condition monitoring for over 20 years. A 1993 article, in particular, describes a benefit-cost analysis performed for a nationwide RWIS implemented in Finland [Pilli-Sihvola and Toivonen 1993]. This article categorizes benefits in terms of savings in accident costs, vehicle costs, and time costs. Total savings for a single district were estimated at $980,000 per year. The yearly RWIS investment costs and recurring costs were estimated at $60,000 per district and $140,000 per district, respectively. These benefits and costs represent a benefit-cost ratio of 5:1.

There is also a 1995 Finnish article that calculates the socio-economic profitability of an experimental roadway on the southern coast of Finland [Pilli-Sihvola and Lahesmaa 1995]. The experimental roadway includes variable speed limit signs and information boards, which are controlled by an RWIS. The RWIS-controlled road is believed to have an effect on the driving behavior of motorists. Changes in socio-economic costs of traffic are calculated based on the RWIS's effect on average speeds and accident rates. Based on the preliminary estimations performed for this research, it seems the RWIS-controlled road can be a socio-economically profitable investment.

CHAPTER 3. MODEL INPUTS

This chapter discusses the factors that are used as input into the RWIS Decision Support Tool. These factors include characteristics of potential RWIS sites, the highway agency's current winter or storm maintenance expenditures, budgetary constraints, and natural site groupings. To build the model, related data were collected.

Much of the data are based on a low water crossing survey that was sent to 283 maintenance supervisors and 25 maintenance engineers throughout Texas. Over 40 percent of those surveyed responded. Follow-up investigations revealed that those who did not respond generally had no low water crossings within their area of responsibility. The results of this survey were entered into a database. The database was then used to compute accident rates for flooded low water crossings and to develop the low water crossing regression model mentioned in section 3.4.

3.1 POTENTIAL RWIS SITES

Implementing an RWIS requires, first, a listing of every site being considered for RWIS implementation. This list should encompass every site where an RWIS would potentially provide benefits to the agency or to the public. As mentioned earlier, these benefits could include reduced maintenance costs through savings in materials and labor, fewer accidents, and a decreased risk of liability for the agency. This listing of potential sites will provide the decision maker with a clearer understanding of where there are needs for RWIS implementation within their area of responsibility.

3.2 SITE CHARACTERISTICS

Once the list of potential sites has been established, there are some basic site characteristics that need to be collected as well. These characteristics include the following:

- type of site (e.g., bridge, low water crossing, high pass)
- site location (district, county, intersection)
- distance of site from nearest maintenance office
- average annual daily traffic (AADT)

Knowing these characteristics will help determine the potential indirect and social savings of an RWIS implementation; they will also be used to help prioritize which sites should receive an RWIS. A sample set of site characteristic data is included below in Table 3.1.

Table 3.1 Site characteristic data

District	County	Location	Type	Distance (km/miles)	AADT
Atlanta	Harrison	FM 449 @ Page Creek Bottom	lwc	27/17	50
Atlanta	Harrison	US 80 W @ Cold Water Creek	lwc	13/8	400
Austin	Blanco	FM 962 @ Cyprus Creek	lwc	30/19	170
Austin	Blanco	FM 1623 @ Big Creek	lwc	30/19	600

3.3 SITE HISTORY

Besides site characteristics, there is also a need for historical data about each site. The data that need to be collected include the following:

- frequency of flood events or winter storm events for each site
- frequency of fatal accidents resulting from icing or flooding at each site
- frequency of injury accidents resulting from icing or flooding at each site
- frequency of property damage accidents resulting from icing or flooding at each site

The above information should be based on data collected over the previous thirty years, or since the bridge or low water crossing was last reconstructed, whichever is the lesser. As with the site characteristics, these historical data will be used to determine the potential indirect and social savings of an RWIS implementation and will help prioritize which sites should receive an RWIS. A sample set of historical data for a five-year period is included in Table 3.2.

Table 3.2 Historical data (five-year period)

District	County	Location	Freq	Fatal	Injury	PDO
Atlanta	Harrison	FM 449 @ Page Creek Bottom	10	0	0	0
Atlanta	Harrison	US 80 W @ Cold Water Creek	10	0	0	0
Austin	Blanco	FM 962 @ Cyprus Creek	12	0	0	2
Austin	Blanco	FM 1623 @ Big Creek	7	0	0	0

3.4 CURRENT WINTER OR STORM MAINTENANCE EXPENDITURES

Other types of data that will be considered during the implementation of the RWIS Decision Support Tool are the agency's current expenditures for either winter maintenance or storm water management. The type of data required will depend on the type of RWIS application being considered for implementation.

If a bridge ice detection system is being considered, then the model will require such winter maintenance data as the number of labor hours and truck hours and the amount of de-icing materials used per storm on the areas that will be influenced by the RWIS. The model will also require an estimate of the agency's unit costs for man-hours, truck-hours, and de-icing materials. These data will be used to estimate the indirect benefits of a bridge ice detection system.

If a low water crossing monitoring system is being considered, then the model will require information about the agency's current storm water management procedures. This information may include such things as the amount of time the agency currently spends patrolling low water crossings for potential flooding, and the number of maintenance workers and vehicles involved in such patrols. This information will be used to estimate the indirect benefits of a low water crossing monitoring system.

3.5 BUDGETARY CONSTRAINTS

Most agencies fund RWIS projects through their existing highway maintenance budgets. Some iteration will be required to balance competing budget demands for the complete infrastructure management function. The agency should first determine whether any RWIS investment is economically feasible in its jurisdiction. Most RWIS installations involving ice detection cost in the range of $10,000 to $40,000 per site, plus require an initial investment of about $25,000 for the necessary communications equipment and a central processing unit (CPU) equipped with RWIS software. An RWIS that monitors low water crossings is slightly cheaper, costing only about $5,000 to $20,000 per site plus an initial investment of about $10,000 for the communications equipment and a CPU with software. It should be noted that neither of these estimates includes the cost of meteorological services, which can range from $50 to $600 per site per month, or the cost for a turnkey installation, which is optional. Meteorological services for ice detection are generally more expensive than those for flood warning systems because they include forecasts of pavement temperatures and conditions. Such forecasts can be very complicated and expensive.

States such as Colorado, Minnesota, Illinois, Michigan, and Iowa have typically implemented bridge ice detection systems at the district level. This is partly because district budgets are used to finance the systems, and partly because bridge ice detection systems can cover large areas with only a few installations. Many of these states have opted to start with just a few RWIS installations, until they become more familiar with how to use them. After one or two winter seasons, these states installed bridge ice detection systems at additional sites while integrating them into the original RWIS [CDOT 1993, MnDOT 1993].

Experience in Texas has shown low water crossing monitoring systems to be affordable enough to be implemented at the county or area level and at as many as 30 sites. A reason for this is that, in Texas, flooding tends to be more localized than freezing conditions, which arrive over broad fronts. The number of low water crossing sites being monitored depends on the size of the county, the RWIS budget and the extent of flooding in the area of responsibility.

In the case of ice detection, at least $40,000 is required as an initial investment for an RWIS that includes a CPU (with software), communications equipment, and remote sensing equipment at one or more sites. In the case of low water crossing monitoring, at least $20,000 is required as an initial investment for an RWIS that includes a CPU with software, communications equipment, and remote sensing equipment at one or more sites. After the initial investment, other remote monitoring sites can be integrated into the RWIS at a low cost, since the basic RWIS infrastructure will already be in place.

3.6 GROUPING OF SITES

One possible method for reducing the cost of the RWIS implementation is to group sites together. This can be done when potential sites are close together and interdependent so that RWIS data collected at one site are normally representative of the conditions at the other sites within the group. Group sizes should be limited to about 5 or 10 sites; for groups larger than that, it becomes difficult to obtain an accurate group representation from just one site. The site that is most likely to ice or flood should be monitored.

An example of a site grouping is the low water crossing monitoring installation on Spicewood Springs Road in Austin, Texas. Figure 3.1 shows the geometry of Spicewood Springs Road and the location of the low water crossings and changeable message signs. The section of road being monitored is a 8-km (5-mile) stretch having seven low water crossings, all from the same creek. Because the second crossing from US 183 is usually the first crossing to flood, it was selected as the site to be monitored. When the water level at this crossing reaches the road, a radio signal is sent from the RPU to two changeable message signs installed at both ends of Spicewood Springs Road. The radio signal activates flashing lights on the message signs to warn the motorists that the water is approaching a dangerous level. When the water rises to a level of 15.24 cm (6 in.) above the road, a radio signal from the RPU changes the message on the two message signs to announce that the road is closed. The radio signals are also sent from the RPU to the Emergency Operating Center in downtown Austin, notifying the City of Austin that the signs have been activated. Figure 3.2 shows one of the changeable message signs at the Spicewood Springs location.

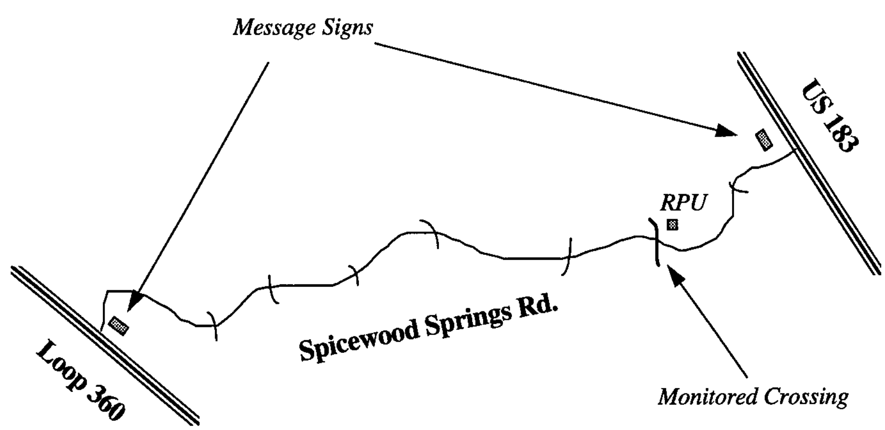

Figure 3.1 Spicewood Springs Road low water crossings

Figure 3.2 Changeable message sign on Spicewood Springs Road.

In order to take advantage of the savings realized by grouping sites, the list of potential sites should, if possible, be partitioned into groups, with one of the sites from each group being identified as the site to be monitored. Of course, it is not always possible to place every site into a group, since some of the potential sites are isolated and must be treated as separate entities. Local weather patterns and geography will influence this decision. Where isolated and intense storms are common, grouping may be less feasible than in areas where larger-scale weather patterns prevail.

3.7 LEVEL OF AGGREGATION

Table 3.3 presents a breakout of the data that should be collected and input into an RWIS Decision Support Tool. The table includes the level at which the data are aggregated, the type of data collected, and how the decision tool uses the data at that level.

Table 3.3 RWIS Decision Support Tool input data

Level of Aggregation	Type of Data	How Data are Used
State	• Aggregation of all data	• Budget establishment
District	• Budget information • Number and groupings of potential RWIS sites (snow/ice) • Aggregated accident data (snow/ice) • Aggregated frequency data (snow/ice) • Winter maintenance expenditures	• Project scheduling • Allocation of funds • Fixed RWIS costs • Social savings (snow/ice) • Indirect savings (snow/ice)
County	• Number and groupings of potential RWIS sites (floods) • Aggregated accident data (floods) • Aggregated frequency data (floods) • Flood warning expenditures	• Project prioritization • Social savings (floods) • Indirect savings (floods)
Group of Sites	• Primary site to be monitored in group • Group membership	• Costs and benefits aggregated for group
Site	• Location • Type of site • Frequency of events • Accident data • AADT • Distance from Maintenance Office	• Site-related costs and benefits • Ranking of sites by need

CHAPTER 4. RWIS LIFE-CYCLE COST MODEL

This chapter describes the life-cycle cost model used by the RWIS Decision Support Tool. This model is used to quantify the costs and benefits associated with RWIS implementation and to compute the net present worth of an RWIS installation. The net present worth of an installation can then be compared against the net present worth of other alternatives to make prioritization and installation decisions. This chapter also presents the low water crossing regression model used by the RWIS Decision Support Tool and describes how it can be used. The regression model allows decision makers to rank by need a large list of potential low water crossing monitoring sites using a simple formula. This ranked list can be used either in conjunction with the net present worth process or as a simple alternative to the net present worth process.

This chapter opens with a description of the RWIS cost elements considered in the model, and then provides methods for estimating RWIS costs and savings for each cost element. Next, it discusses the life-cycle cost analysis of RWIS implementation and provides a methodology for calculating net present worth of various alternatives. Also presented is the low water crossing site prioritization model and its application. Finally, the chapter concludes by describing how the RWIS Decision Support Tool can be implemented at both the project and network levels. A flow diagram of the RWIS Decision Tool process is included in Figure 4.1.

4.1 RWIS COST ELEMENTS

The costs that are affected by the implementation of an RWIS can be categorized as direct costs, indirect costs, and social costs. This section explains what each of these costs includes and how these costs will be affected by RWIS implementation.

4.1.1 Direct Costs

Direct costs — those costs that are directly related to the acquisition and maintenance of the RWIS — include capital costs and annual costs. Capital costs are those costs associated with the purchase and installation of RWIS equipment, including hardware and software. Capital costs also include the cost of updating RPUs and CPUs. Annual costs encompass recurring RWIS costs, such as routine operations and maintenance costs, project administration costs, and the costs of meteorological services. Operating and maintenance costs, which will be incurred throughout the life cycle of an RWIS, include such things as replacing RWIS equipment and performing maintenance on RWIS software. The costs of meteorological services include the costs associated with services that provide weather forecasts, live radar, and satellite images. As with operating and maintenance costs, these service costs will continue throughout the life cycle of an RWIS. When a highway agency implements an RWIS, it can expect its direct costs to increase significantly; such costs, however, will be offset by a significant reduction in indirect costs and social costs.

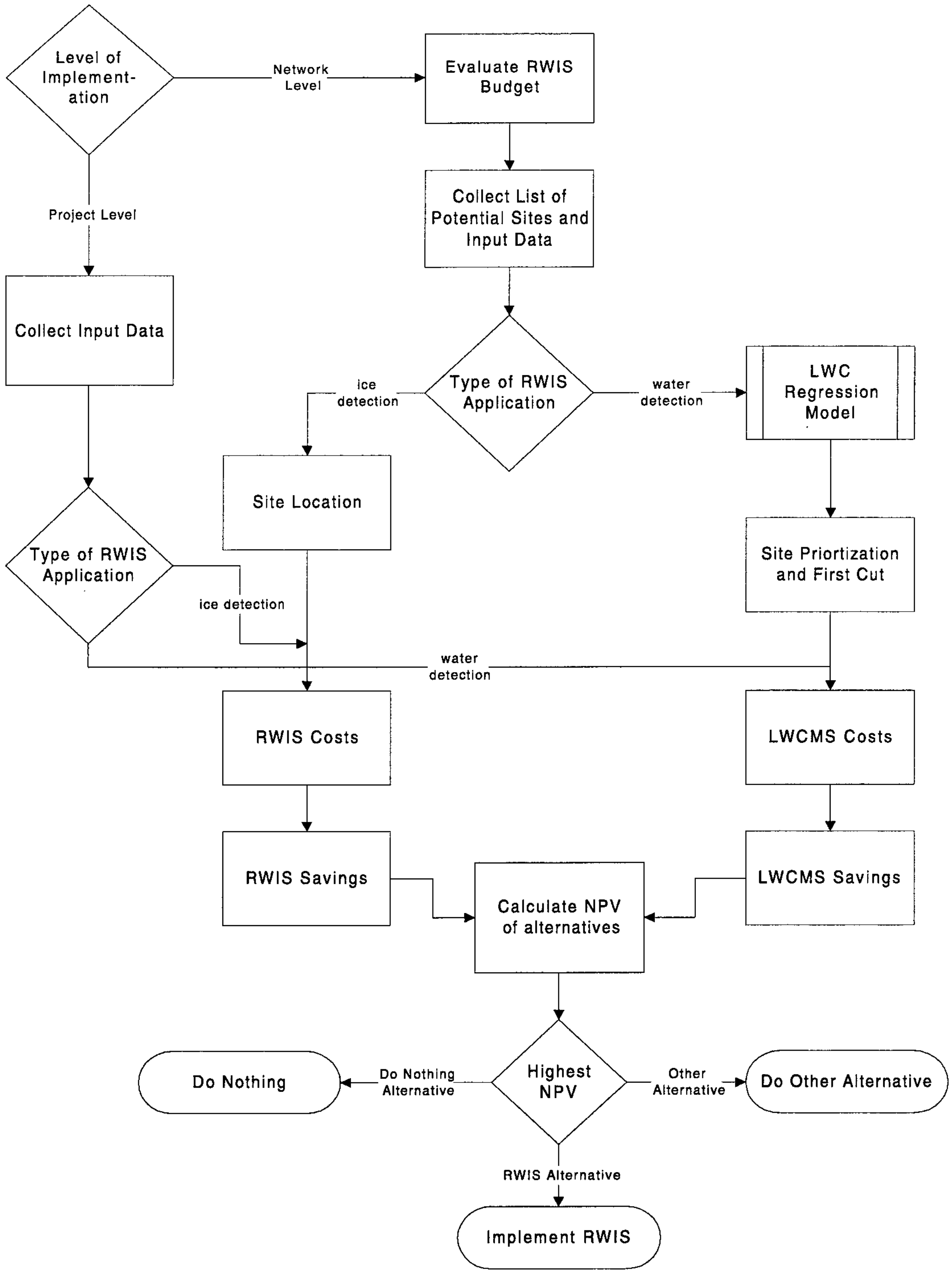

Figure 4.1 RWIS Decision Tool process

4.1.2 Indirect Costs

Indirect costs are those costs incurred by the highway agency that are indirectly affected by the implementation of an RWIS. These costs include winter or storm maintenance costs and the costs of lawsuits resulting from hazardous road conditions. Winter or storm maintenance costs will be significantly reduced with the addition of an RWIS — a result of maintenance crews being better informed of current and future road conditions. As mentioned earlier, real-time information provided by the RWIS eliminates the need for patrolling trips to check on remote sites, since the information is available at the maintenance office. Also, knowledge of future road conditions allows decision makers to optimize the scheduling of maintenance crews and to pretreat roads — activities that can reduce expenditures for labor, equipment, and materials.

Secondly, the implementation of an RWIS will not only ensure safer driving conditions; it should also decrease the risk of litigation resulting from hazardous road conditions. For example, RWIS historical data provide documented proof of all de-icing treatments undertaken during a storm event. Thus, if a motorist had a wreck on a bridge and claimed that it had not been de-iced, then the highway agency could look at the RWIS pavement data to verify if any de-icing treatments had been made. If the agency sees that the chemical content went from 10 percent to 90 percent, it could show that the bridge had indeed been treated.

Unfortunately, it is almost impossible to quantify this type of indirect savings. If there were evidence proving that liability risk was correlated with the number of automobile accidents, it could be possible to quantify these savings by making the risk of a lawsuit proportional to the expected number of accidents. But since there is no evidence that this is the case, we cannot quantify indirect savings in this manner. For this reason, the RWIS Decision Support Tool will not attempt to quantify savings resulting from reduced risk of liability. Instead, reduced liability risk will be treated as a qualitative factor in the economic assessment of an RWIS.

4.1.3 Social Costs

Social costs are those costs that are incurred by the public or by the environment. These costs include accident costs, pollution costs, and travel costs. Accident costs are the estimated public costs of automobile accidents. The three types of accidents that will be analyzed in this study include fatal, injury, and property damage. A 1993 study undertaken by the University of Wyoming found that over 60 percent of the accidents occurring on Interstate 80 between Laramie and Cheyenne occurred during poor road and travel conditions, which was only 10 percent of the time [French and Wilson 1993]. This finding indicates a potential for large social savings if an RWIS can significantly reduce the risk of accidents during poor travel conditions.

Travel costs are the costs associated with delays caused by increased traffic or road closures. Pollution costs refer to the harmful vehicle emissions released into the environment as a result of increased travel time. Pollution costs can also include the harmful effects that de-icing agents can have on the environment. RWIS implementation will result in a slight reduction in both of these costs by improving the flow of traffic during inclement conditions and by reducing the amount of de-icing materials used per storm. Given that prior research from Wisconsin [Hanbali 1994] and Finland [Pilli-Sihvola and Lahesmaa 1995] has found that this reduction is negligible compared with other RWIS costs and savings, the RWIS Decision Support Tool will not attempt to quantify travel costs or pollution costs in its cost model. Instead, reduced travel costs and pollution costs will be treated as a qualitative factor in the economic assessment of an RWIS.

4.2 METHODS FOR ESTIMATING RWIS COSTS AND SAVINGS

In order to perform a benefit-cost analysis, one must first attempt to quantify the associated costs and potential savings that result from implementing an RWIS. Owing to the unique nature of the two different types of RWIS applications, the methods for determining costs and savings associated with each will be presented in separate sections of this report. The methods for estimating RWIS costs and savings for ice detection applications are described in section 4.2.1, whereas the methods for estimating costs and savings associated with low water crossing monitoring applications are described in section 4.2.2.

4.2.1 Estimating Costs and Savings for Ice Detection Systems

The three categories of costs and cost savings for bridge ice detection systems include direct costs, indirect cost savings, and social cost savings. The methods for estimating each of these categories are explained below.

4.2.1.1 Estimating Direct Costs for Ice Detection Systems: Direct costs of bridge ice detection systems can be easily acquired. As mentioned above, direct costs include capital costs and annual costs. Estimates for capital costs (RWIS equipment and installation) and the annual costs for meteorological services can obtained directly from any number of various RWIS vendors. These costs will vary depending on the level of RWIS service and on the complexity of the system. In general, though, the complete RWIS system for ice detection includes pavement sensors, atmospheric sensors, a remote processing unit (RPU), a central processing unit (CPU), RWIS software, communications equipment, and weather and pavement forecasts. Estimates for these costs were given in section 2.5.

It is estimated that the complete life cycle of an RWIS is 25 years, after which time the entire system will need to be replaced. Also, RPUs and CPUs will need to be upgraded or replaced every five years or so in order to keep up with technological advances. While these costs would be included in the capital costs, they should be adjusted using the discount factor when calculating the net present value of the system.

Operating and maintenance cost estimates can be obtained from highway agencies that have experience using an RWIS. For example, the Colorado Department of Transportation (CDOT) reported its average annual maintenance costs to be $6,200 for eight RWIS roadside installations [CDOT 1993]. These costs took into account calibration, equipment repairs, and replacement of damaged equipment. On average, CDOT has had two or three pavement sensors and a modem or radio replaced each season [CDOT 1993].

Unlike Colorado, most states purchase some type of maintenance contract from the vendor. Under the terms of these contracts, the vendor receives an annual fee in exchange for repairing, replacing, or calibrating RWIS components when necessary. Based on the experiences of other state DOTs, the cost of these maintenance contracts ranges from about $1900 to $4100 per RPU site per year. Thus, the average maintenance contract is estimated to be about $3000 per RPU per year.

Finally, there may be some costs associated with the day-to-day operation of the system (e.g., long distance phone charges). The total annual operations and maintenance cost of the system will be the sum of the estimated annual maintenance cost ($3000 per RPU site) and any other costs associated with the operation of the system, such as long distance phone calls. This is expressed in the following equation.

Annual O&M Costs = [$3000 * (# of RWIS sites)] + (Phone Charges) (4.0)

4.2.1.2 Estimating Indirect Cost Savings for Ice Detection Systems: Indirect costs and savings are slightly more difficult to calculate. The only quantifiable area of indirect cost savings obtained by implementing an RWIS for ice detection will be in reduced winter maintenance costs. Baseline annual winter maintenance costs can be extrapolated from an agency's expenditures on winter and maintenance in prior years. For instance, the routine maintenance expenditures of TxDOT are tracked by a computerized management system called the Maintenance Management Information System (MMIS). MMIS data can be reported in several formats, both at the statewide and district levels. Each of these formats allows expenditures to be subdivided into labor, equipment, and material costs. The number of TxDOT man-hours for each activity is also reported in a separate column in this report. MMIS can be used to compute an average annual maintenance cost for any district or county in Texas.

These average annual winter maintenance costs can be categorized into labor, equipment, and materials costs. Labor costs will be based on the number of man-hours spent per year on winter or storm maintenance. Equipment costs will be based on the number of hours a piece of storm maintenance equipment (e.g., a snowplow or truck) is used annually. Finally, materials costs will be based on the number of tons of de-icing or anti-icing materials used per year. The average yearly total for man-hours, equipment hours, and tons of de-icing materials should be calculated so that their associated annual costs can be used to compute fixed unit costs, such as those shown in Table 4.2. These unit costs will vary from district to district.

Table 4.2 MNDOT unit costs

Unit	Cost
Man-hours	$25.50
Truck-hours	$24.00
Sand/ton	$8.26
Salt/ton	$28.50

The unit costs in Table 4.2 are based on 1993 Minnesota Department of Transportation (MNDOT) data [MnDOT 1993]. If an agency does not have or is unable to compute its own unit costs, these can be used as substitutes. The labor cost from Table 4.2 includes base salary, fringe benefits, overhead, and overtime differential. Overtime differential is based on the assumption that 2/3 of the hours worked are paid as straight time and 1/3 as overtime. The unit cost of the truck, which is based on current equipment charges in Minnesota, includes the depreciation of the vehicle, plow, spreader, and such operating costs as fuel, oil, tires, and repairs. Once an agency has established its unit costs for winter maintenance activities and its annual winter maintenance expenditures for labor, equipment and materials, it can calculate the indirect savings associated with RWIS implementation.

Winter maintenance savings resulting from the implementation of an RWIS will be realized in a variety of forms. First of all, the need for routine patrolling should be eliminated in areas where RWIS sites have been installed. This type of savings can be calculated as follows. Using the unit costs from Table 4.2, the cost for one patrol shift can be calculated by multiplying the length of a shift (eight hours) by the hourly labor cost and the hourly truck cost.

Cost/patrol shift = 8 hrs * [(# of workers/crew * $25.50/hr) + $24/hr] (4.1)

In the case of a crew with one worker, an agency would save $396 for every patrolling shift that the RWIS implementation eliminated. By determining the number of patrol shifts per storm that are no longer needed in the areas under RWIS influence, and by multiplying it by the number of storms per year and the cost per shift, one can calculate the annual savings obtained by reduced patrolling. This is summarized in Equation 4.2.

Patrol savings = (# of eliminated patrol shifts/storm)
(# of storms/year)(cost/shift) (4.2)

Secondly, RWIS implementation should result in a reduction in labor hours and equipment hours for each storm by improving the ability to schedule and manage crews and by reducing the number of winter maintenance passes required during each storm. The Wisconsin DOT reported saving more than 600 man-hours during one winter season with a statewide RWIS. This translated to savings of about four hours of labor per worker during each winter storm [Morris 1994]. Assuming that the duration of an average storm is 24 hours and that winter maintenance operations are underway throughout the storm's duration, this indicates a 16.7 percent reduction in labor costs obtained by the implementation of an RWIS. This number is consistent with Strategic Highway Research Program (SHRP) research findings that there is about a 15 percent reduction in the required number of winter maintenance passes during a storm with the implementation of RWIS and anti-icing strategies [SHRP 1994]. Thus, we can confidently assume that implementation of an RWIS will reduce our labor and equipment costs for storm events by 15 percent in the areas under RWIS influence. By "areas under RWIS influence," we are referring to any truck routes that are using RWIS data to plan maintenance operations.

Using Table 4.2, labor savings can be estimated as follows:

Labor Savings = 0.15 * (avg. # of labor hours/storm on RWIS routes)
* ($25.50/hr) * (avg. # of storms/year) (4.3)

Using Table 4.2, equipment savings can be estimated as follows:

Equipment Savings = 0.15 * (avg. # of truck hours/storm on RWIS routes)
* ($24/hr) * (avg. # of storms/year) (4.4)

Finally, RWIS implementation will result in savings through more efficient use of de-icing materials. The Wisconsin DOT reported saving over $75,000 in salt during one winter storm after implementing a statewide RWIS [Morris 1994]. The Nevada DOT also saw a significant reduction in its chemical usage when RWIS technologies were implemented and used in conjunction with anti-icing strategies [NDOT 1995]. (Anti-icing is the process of applying chemicals to the roadway before the ice bond has had a chance to form.)

There are a number of materials and chemicals that can be used for de-icing or anti-icing pavements. These include sand, salt, and chemical compounds like magnesium chloride. Because these materials have varying costs associated with them, the amount of materials savings that an agency realizes will depend on the combination of de-icing or anti-icing materials used. An agency can look at past maintenance records to determine how many tons per storm of de-icing materials they have used in previous years. Since the SHRP study determined that proper usage of an RWIS can result in 15 percent fewer maintenance passes per storm, we can assume that 15 percent less de-icing or anti-icing materials will be used per storm in the areas under RWIS coverage. The materials savings from RWIS implementation can be estimated as follows.

Materials Savings = (0.15) * (tons/storm of de-icing materials used on RWIS routes)
* (Cost of material/ton) * (avg. # of storms/year) (4.5)

The total winter and storm maintenance savings resulting from RWIS implementation will be the sum of the four types of savings mentioned above.

S_m = Savings from reduced winter maintenance costs
S_m = (patrol savings) + (labor savings) + (equipment savings)
+ (materials savings) (4.6)

4.2.1.3 Estimating Social Cost Savings for Ice Detection Systems: The primary manner in which bridge ice detection systems result in social cost savings is by reducing the number of automobile accidents that occur during icy or snowy conditions. Reduced accident costs realized by RWIS implementation can be estimated by taking a standard cost for each type of accident and multiplying that cost by the expected reduction of those types of accidents through RWIS implementation. Table 4.3 shows the 1988 Federal Highway Administration (FHWA) cost estimates for various types of accidents, ranging from fatal to property damage only [FHWA 1988]. The 1988 FHWA estimate was based on the costs of medical expenses, wage loss, insurance administration costs, and motor vehicle property damage costs. The RWIS Decision Support Tool will use the 1988 FHWA estimate as the basis in traffic-accident-cost-related calculations.

Table 4.3 1988 FHWA estimate of accident costs

Accident Type	Cost in 1988 Dollars
Fatal	$1,700,000
Injury	$14,000
Property Damage	$3,000

The expected annual number of each type of accident occurring during inclement conditions will depend on the number of vehicles exposed to inclement conditions and on the likelihood that each type of accident will occur during inclement conditions. This relationship can be expressed as:

$$E(A_i) = \text{Exposure} * AR_i \tag{4.7}$$

where

$E(A_i)$ = expected # of accidents of type i during inclement conditions (acc/year),

Exposure = # of vehicle-miles traveled during inclement conditions (veh-mi/year), and

AR_i = Accident Rate for type i accident during inclement conditions (acc/veh-mi).

A 1994 SHRP research project analyzed maintenance data obtained from five storms during the 1991-92 winter to determine what improvement in pavement conditions can be expected from RWIS implementation and anti-icing operations [SHRP 1994]. Two of these storms occurred in Nevada, two in New York, and one in Ohio. These data indicate that areas not under RWIS coverage have ice- and snow-covered pavements for approximately 50 percent of the time during storm periods. These data also indicated that areas under RWIS coverage have ice- and snow-covered pavements for only 40 percent of the time. We will assume that the pavement condition is wet for the remainder of the time during storm periods. Thus, for areas not under RWIS coverage, the pavement condition is icy for 50 percent of the time and wet for the other 50 percent of the time. For areas under RWIS coverage, the pavement condition is icy for 40 percent of the time and wet for the remaining 60 percent of the time.

Using the results of the SHRP research, the annual vehicle-miles of travel during exposure to icy and wet road conditions can be estimated as follows for the areas under RWIS consideration.

With RWIS implementation:

$$\text{Exposure to Ice} = 40\% * (\text{AADT} * \text{Freq} * \text{L}) \tag{4.8}$$

$$\text{Exposure to Wetness} = 60\% * (\text{AADT} * \text{Freq} * \text{L}) \tag{4.9}$$

Without RWIS implementation:

$$\text{Exposure to Ice} = 50\% * (\text{AADT} * \text{Freq} * \text{L}) \tag{4.10}$$

$$\text{Exposure to Wetness} = 50\% * (\text{AADT} * \text{Freq} * \text{L}) \tag{4.11}$$

where

Exposure to Ice = # of vehicle-miles traveled during icy conditions (veh-mi/year),

Exposure to Wetness = # of vehicle-miles traveled during wet conditions (veh-mi/year),

AADT = Annual Average Daily Traffic (veh/day),

Freq = Annual number of storm days (days/year), and

L = Length of RWIS road coverage (miles).

This same SHRP research project analyzed accident data on five freeways in Monroe County, New York, for the 1989-90 and 1990-91 winters to determine the variation of accident rates as a function of pavement surface condition. It was determined that ice- and snow-covered pavements experience 4.6 accidents per million vehicle miles, wet pavements experience 2.3 accidents per million vehicle miles, and dry pavements experience 0.6 accidents per million vehicle miles. Thus, accidents on snow- or ice-covered roads are twice as likely as those on wet pavements and 8 times more likely than those on dry pavements. These findings are consistent with a City of Milwaukee study that analyzed traffic accident data in Wisconsin, New York, and Illinois. The study found that winter road maintenance operations reduce accident rates by at least 80 percent when bare pavement is achieved [Hanbali 1994]. Another study performed in Wyoming determined that accident rates are reduced from 11.6 accidents per million vehicle miles on icy pavement to 0.9 accidents per million vehicle miles on dry pavement [French and Wilson 1993], corresponding to an accident rate reduction of over 90 percent.

Based on California Department of Transportation data, the severity distribution of freeway accidents is 3.2 percent fatal, 44.6 percent injury, and 52.2 percent property-damage-only accidents [California Department of Transportation 1988]. Using this distribution and the accident rates found in the SHRP study, we can compute three types of accident rates for various road conditions. These accident rates are given in Table 4.4. It is important to note that these accident rates are based on historical data obtained from New York, and that the actual accident rates for different geographical areas may vary from these estimates owing to varying driver characteristics.

Table 4.4 Accident rates (per million veh-miles) from SHRP study

Conditions	Fatal	Injury	Property Damage
icy	0.150	2.10	2.40
wet	0.074	1.00	1.20
dry	0.019	0.27	0.31

Using these accident rates and Equation 4.7, we can now compute the expected number of fatal, injury, and property damage accidents that occur during inclement conditions for the area under RWIS consideration. These can be calculated as follows.

$$E(A_F) = [(\text{Exposure to Ice} * .15) + (\text{Exposure to Wetness} * .074)] * 10^{-6} \quad (4.12)$$

$$E(A_I) = [(\text{Exposure to Ice} * .21) + (\text{Exposure to Wetness} * .10)] * 10^{-6} \quad (4.13)$$

$$E(A_{PD}) = [(\text{Exposure to Ice} * .24) + (\text{Exposure to Wetness} * .12)] * 10^{-6} \quad (4.14)$$

where

$E(A_F)$ = Expected # of fatal accidents,

$E(A_I)$ = Expected # of injury accidents, and

$E(A_{PD})$ = Expected # of property damage accidents.

Here "Exposure to Ice" and "Exposure to Wetness" are calculated using Equations 4.8 and 4.9, respectively, with RWIS implementation, and Equations 4.10 and 4.11, respectively, without RWIS implementation. The difference between the expected number of accidents without an RWIS and with an RWIS is equal to the expected number of accidents reduced through RWIS implementation. This is illustrated in the following equations.

$$R(A_F) = [(.15)(.5)(AADT * Freq * L) + (.074)(.5)(AADT * Freq * L)] - [(.15)(.4)(AADT * Freq * L) + (.074)(.6)(AADT * Freq * L)] * 10^{-6} = .0076\,(AADT * Freq * L) * 10^{-6} \quad (4.15)$$

$$R(A_I) = [(.21)(.5)(AADT * Freq * L) + (.10)(.5)(AADT * Freq * L)] - [(.21)(.4)(AADT * Freq * L) + (.10)(.6)(AADT * Freq * L)] * 10^{-6} = .011(AADT * Freq * L) * 10^{-6} \quad (4.16)$$

$$R(A_{PD}) = [(.24)(.5)(AADT * Freq * L) + (.12)(.5)(AADT * Freq * L)] - [(.24)(.4)(AADT * Freq * L) + (.12)(.6)(AADT * Freq * L)] * 10^{-6} = .012(AADT * Freq * L) * 10^{-6} \quad (4.17)$$

where

$$R(A_F) = \text{Annual reduction in fatal accidents with RWIS,}$$

$$R(A_I) = \text{Annual reduction in injury accidents with RWIS, and}$$

$$R(A_{PD}) = \text{Annual reduction in property damage accidents with RWIS.}$$

Using the accident costs from Table 4.3, we can use the following formula to calculate an estimate for accident savings:

$$S_A = \Sigma_i \, [R(A_i) * \text{Cost}_i] \tag{4.18}$$

where

$$S_A = \text{Annual Accident Savings (\$/year),}$$

$$R(A_i) = \text{Annual reduction in type i accidents with RWIS, and}$$

$$\text{Cost}_i = \text{Cost of type i accident (\$/accident).}$$

When we substitute Equations 4.15, 4.16, and 4.17 and the costs from Table 4.3 into Equation 4.18, we get the following simplified equation for estimating accident savings associated with RWIS implementation.

$$S_A = 0.013 \text{ (\$/veh-mile)} * \text{ (AADT * Freq * Length)} \tag{4.19}$$

where

AADT = Annual Average Daily Traffic (veh/day),

Freq = Annual number of storm days (days/year), and

Length = Length of RWIS road coverage (miles).

It is important to note that some of the parameters used to derive this equation (such as accident rates under various pavement conditions) may have a significant amount of variance. Therefore, the accuracy of the estimate for annual accident savings is only reliable within an order of magnitude.

4.2.1.4 Other Benefits of Ice Detection Systems: There are other benefits associated with the implementation of bridge ice detection systems that are not included in the RWIS cost benefit model because of the difficulty in quantifying these benefits. Although these benefits will not be reflected in the net present value of the system, they should nonetheless be considered in the RWIS decision-making process.

These intangible benefits include reduced risk of liability, improved planning of construction projects, and reduced travel time and pollution costs. As discussed in section 4.1.2, bridge ice detection systems help reduce the likelihood of litigation by keeping historical records of de-icing procedures and by reducing the public's exposure to hazardous conditions.

Improved planning of construction projects results from the ability of maintenance crews to use an RWIS to forecast the weather and pavement conditions for that day. This will allow them to better schedule such maintenance activities as repaving or restriping roads, which are dependent on favorable weather conditions.

Finally, bridge ice detection systems will improve traffic flow during inclement weather and reduce the amount of de-icing chemicals used per snowstorm. This will result in travel time savings for motorists and less damage to the environment.

4.2.2 Estimating Costs and Savings for LWCMSs

As with the bridge ice detection systems, the three categories of costs and cost savings that result from implementation of low water crossing monitoring systems are direct costs, indirect cost savings, and social cost savings. The methods for estimating each of these categories are slightly different than those used for bridge ice detection systems, as explained below.

4.2.2.1 Estimating Direct Costs for an LWCMS: Direct costs of low water crossing monitoring systems can be easily acquired. As mentioned above, direct costs include capital costs and annual costs. Estimates for capital costs (LWCMS equipment and installation) and the annual costs for meteorological services can be obtained directly from any number of various LWCMS vendors. These costs will generally be lower than the direct costs and service costs for bridge ice detection systems, given that LWCMSs do not require as many atmospheric sensors and require no pavement forecasts.

It is assumed that the entire LWCMS will need to be replaced every 25 years (the expected life cycle of the system). Also, RPUs and CPUs will need to be upgraded or replaced every five years or so in order to keep up with technological advances. These costs should be included in the capital costs, but should be adjusted using the discount factor when calculating the net present value of the system.

Operating and maintenance cost estimates for an LWCMS can be obtained from highway agencies having experience using these systems. The City of San Antonio has recently installed LWCMS devices at 18 sites throughout the San Antonio area. City officials anticipate their average annual costs to be about 5 percent of their total capital costs [Nelson Ciffel, City of San Antonio, phone interview, 13 March 1997]. This figure is based on what the vendor would have charged them for a full maintenance contract that covers repairing, replacing, or calibrating RWIS components when necessary. Of this 5 percent, the City of San Antonio estimates that 60 percent of the operations and maintenance costs will be spent on equipment replacement, and 40 percent will be spent on the labor involved in replacing, repairing, or calibrating the equipment [Ciffel 1997].

Also, there may be some costs associated with the day-to-day operation of the system, such as long distance phone charges (if that type of communication is being used). The total annual operations and maintenance cost of the system will be the sum of the estimated annual maintenance cost (5 percent of capital costs) and any other costs associated with operation of the system, such as long distance phone calls. This is expressed in the following equation:

Annual O&M Costs = [5% * (Total Capital Costs)] + (phone charges) (4.20)

4.2.2.2 Estimating Indirect Costs and Savings for LWCMS: The main area of indirect savings from an LWCMS is in reduced patrolling and road maintenance during rainstorms. Since the maintenance supervisor will be provided with real-time information about the status of the low water crossings from the LWCMS, he/she will not need to send maintenance crews out to the sites unless a problem has been reported at that specific site. This information will allow the crews to spend their time more efficiently on sites that need their attention. Also, if a site is equipped with active message signs like the ones on Spicewood Springs Road, then maintenance crews will not be required to manually open and close roads that are flooded — the signs can do this automatically. Savings realized through the reduced patrolling can be calculated in a manner similar to that shown in Equation 4.1, using the unit costs from Table 4.2.

Cost/patrol shift = 8 hrs * [(# of workers/crew * $25.50/hr) + $24/hr] (4.1)

In the case of a crew with one worker, an agency would save $396 for every patrolling shift that the LWCMS eliminated or allowed to be reassigned to other areas. By determining the number of patrol shifts per storm that can be eliminated or reassigned as a result of LWCMS information, and by multiplying it by the number of storms per year and the cost per shift, one can calculate the annual savings that accrue through reduced patrolling. This was summarized in Equation 4.2.

Patrol savings = (# of eliminated patrol shifts/storm) * (# of storms/year)* (Cost/shift) (4.2)

Since this is the only quantifiable area of indirect savings associated with implementation of an LWCMS, the total indirect savings from LWCMS implementation can be expressed as follows:

S_m = Savings from reduced storm maintenance costs = (patrol savings) (4.21)

4.2.2.3 Estimating Social Costs and Savings for an LWCMS: The primary manner in which an LWCMS accrues social cost savings is by reducing the number of automobile accidents that occur at flooded low water crossings during or after strong rain storms. Reduced accident costs resulting from LWCMS implementation can be estimated by taking a standard cost for each type of accident and multiplying that cost by the expected reduction of those types of accidents through LWCMS implementation. The 1988 FHWA cost estimates given in Table 4.3 can again be used to calculate accident savings associated with an LWCMS.

When an LWCMS has been implemented, the amount of time drivers are exposed to hazardous conditions without warning will be reduced significantly. An LWCMS provides highway maintenance crews with real-time information about the status of the low water crossings in their area of responsibility. This information allows them to make decisions regarding public service announcements and road closings before any flooding actually occurs. When active message signs are installed at the site and linked to the LWCMS, the motorist is immediately warned of hazardous conditions and, thus, is never exposed to hazardous conditions unless he/she chooses to ignore the sign. Even if message signs are not at the site, the rise in level sensor readings reported to the maintenance office, complemented with live radar, allows the maintenance supervisor to anticipate when the crossing will become hazardous. With this information, the maintenance office can provide adequate warnings to motorists about the conditions of low water crossings. Accordingly, after implementing an LWCMS, we can expect to eliminate all of the accidents that would have occurred at those flooded low water crossings where motorists were not properly warned.

To accurately estimate the expected number of reduced accidents resulting from LWCMS implementation, we must incorporate a factor that accounts for the large number of motorists that disregard message signs and road barricades. The TxDOT Maintenance Section in Kerr County estimates that 50 percent of all accidents occurring at flooded low water crossings in Kerr County are the result of a motorist driving through a barricade or disobeying a message sign [Wayne Pehl, Maintenance Supervisor, TxDOT Kerrville Office, low water crossing survey interview, 8 May 1997]. The remaining 50 percent occur because the motorist did not receive adequate warning about the status of the crossing. Only those accidents that occur because the motorist is uninformed of flood conditions can actually been prevented using an LWCMS. The percentage of these types of accidents will be referred to in the model as the *preventable factor*. This percentage may vary from county to county.

As mentioned earlier, the expected annual number of each type of accident occurring during inclement weather conditions will depend on the number of vehicles exposed to those inclement conditions and the likelihood that each type of accident will occur during inclement conditions. In Equation 4.7 this relationship was expressed as:

$$E(A_i) = \text{Exposure} * AR_i$$

where

$E(A_i)$ = expected # of accidents of type i during inclement conditions (acc/year),

Exposure = # of vehicle-miles traveled during inclement conditions (veh-mi/year), and

AR_i = Accident Rate for type i accident during inclement conditions (acc/veh-mi).

Since an LWCMS relates only to specific sites and not to stretches of roadway, we must modify the Exposure variable in this equation as follows.

$$E(A_i) = \text{Site Exposure} * AR_i$$

where

$$E(A_i) = \text{expected \# of accidents of type i during flooded conditions (acc/year),}$$

$$\text{Site Exposure} = \text{\# of vehicles crossing site during flooded conditions (veh/year), and}$$

AR_i = Accident rate for type i accident at site during flooded conditions (acc/veh).

The next step in our process is to estimate how many of these expected accidents would be reduced when an LWCMS is implemented. This estimate will depend on the ***preventable factor***, given that disobedience-type accidents cannot be prevented through an LWCMS. The ***preventable factor*** represents the percentage of accidents that occurred when the motorist was not adequately warned. The product of this percentage and the total expected number of accidents represent the maximum number of accidents that can be reduced by using an LWCMS. This is represented in the following equation.

$$R(A_i)_{max} = PF * \text{Site Exposure} * AR_i \qquad (4.23)$$

where

$R(A_i)_{max}$ = maximum # of reduced accidents of type i each year (acc/year), and

PF = Preventable factor (percentage of accidents that could be prevented with warning system).

Of course, not all of these accidents will be reduced with an LWCMS: Even with adequate warning, there will still be those motorists who may try to drive through a flooded low water crossing. Even such extreme measures as barricading the road may not keep all of the motorists from attempting to drive through a flooded low water crossing. Since there are no data regarding motorist behavior at low water crossings, we will have to estimate the likelihood that a motorist will obey a warning or a road barricade and will thus not risk driving through a flooded low water crossing. Our model will refer to this estimate as the *obedience factor* for the likelihood that a motorist will heed warnings or barricades. This estimate will have to be provided by the maintenance supervisor of the given county. Using this estimate, the expected annual reduction in each type of accident can be estimated as follows:

$$R(A_i) = (OF) * (PF * \text{Site Exposure} * AR_i) \qquad (4.24)$$

where

$R(A_i)$ = expected # of reduced accidents of type i each year (acc/year),

PF = Preventable factor (percentage of accidents that could be prevented with warning system), and

OF = Obedience factor (likelihood that a motorist will heed warning).

Site exposure can be calculated by multiplying the AADT of the site by the frequency of flooding at the site by the length of time the site remains flooded each event. This can be expressed as follows:

$$\text{Site Exposure} = \text{AADT} * \text{Freq} * \text{Duration} \tag{4.25}$$

where

AADT = Average Annual Daily Traffic (veh/day),

Freq = Frequency of flooding events (floods/year),

Duration = Length of time vehicles are exposed to flooded conditions (days/flood).

For a site without an LWCMS, a reasonable default value for the Duration variable is four hours (or 1/6 of a day). This estimate is based on information collected during a low water crossing survey of over 200 maintenance supervisors in Texas. These maintenance supervisors estimated that a typical low water crossing remains flooded for at least four hours after a rainstorm. After this time, the water has usually receded to a level that is no longer hazardous to drivers. Of course, in the case of extreme storms, such as an 80-year storm event, a low water crossing may remain flooded for days. Although this is possible, for the sake of simplicity this model will assume that motorists are exposed to 1/6 of a day of hazardous travel each time a low water crossing becomes flooded. This gives us the following simplified equation for Site Exposure.

Site Exposure (veh/year) = ***AADT*** (veh/day) * ***Freq*** (floods/year) * ***1/6*** (days/flood) (4.26)

The next step is to compute accident rates for flooded conditions at low water crossings. This was done for Texas by taking the results of the low water crossing survey and then dividing the total number of fatal accidents, injury accidents, and property damage accidents occurring at each site over the past five years by the estimated ***Site Exposure*** for that site over the past five years; this operation yields an accident rate for each site in the database. These accident rates were then averaged to get three overall accident rates for flooded low water crossings. The accident rates for Texas are shown in Table 4.5.

Table 4.5 Accident rates for flooded low water crossings (per million vehicles traveled)

Fatal	Injury	Property Damage
45.8	39.2	190

Using these accident rates and Equations 4.24 and 4.26, we can now compute estimates for the expected reduction in fatal, injury, and property damage accidents that occur in Texas during flooded conditions due to LWCMS implementation. These estimates can be calculated as follows:

$$R(A_F) = OF * (1 - DF) * (AADT * Freq * 1/6) * (45.8 * 10^{-6}) \tag{4.27}$$

$$R(A_I) = OF * (1 - DF) * (AADT * Freq * 1/6) * (39.2 * 10^{-6}) \tag{4.28}$$

$$R(A_{PD}) = OF * (1 - DF) * (AADT * Freq * 1/6) * (190 * 10^{-6}) \tag{4.29}$$

where

$R(A_F)$ = Annual reduction in fatal accidents with LWCMS,

$R(A_I)$ = Annual reduction in injury accidents with LWCMS, and

$R(A_{PD})$ = Annual reduction in property damage accidents with LWCMS.

In order to calculate annual accident reductions for states other than Texas, specific accident rates for that particular region should be used. If these accident rates are not available, then the Texas accident rates can be used as estimates. Using the accident costs from Table 4.3, we can now use the following formula to calculate an estimate for accident savings through an LWCMS:

$$S_A = \Sigma_i [R(A_i) * Cost_i] \tag{4.30}$$

where

S_A = Accident Savings,

$R(A_i)$ = Annual reduction in type i accidents with LWCMS, and

$Cost_i$ = Cost of type i accident.

When we substitute Equations 4.27, 4.28, and 4.29 and the costs from Table 4.3 into Equation 4.30, we get the following simplified equation for estimating accident savings associated with LWCMS implementation at a site or group of sites:

$$S_A = 13.2 * AADT * Freq * PF * OF \tag{4.31}$$

where

AADT = Average Annual Daily Traffic (veh/day),

Freq = Frequency of flooding events (events/year),

PF = Preventable factor (percentage of accidents that could be prevented with warning system), and

OF = Obedience factor (likelihood that a motorist will heed warning).

It is important to note that some of the parameters used to derive this equation, such as *preventable factor*, *obedience factor,* and *duration,* may have a significant amount of variance. Therefore, the accuracy of the estimate for annual accident savings is only reliable within an order of magnitude.

4.2.2.4 Other Benefits of an LWCMS: There are other benefits associated with the implementation of an LWCMS that are not included in the RWIS cost-benefit model because of the difficulty in quantifying these benefits. Although such benefits will not be reflected in the net present value of the system, they should be considered in the RWIS decision-making process.

These intangible benefits include reduced risk of liability and reduced travel-time costs. A few years ago, the City of San Antonio was held liable in an $8 million lawsuit brought by the family of a woman who had drowned when her Volkswagen was washed away at a flooded low water crossing. The jury found the City of San Antonio liable for not providing the woman fair warning about the dangerous crossing. By providing motorists with advanced warning about hazardous water level conditions, an LWCMS will reduce the likelihood that a similar lawsuit will be brought against TxDOT.

Motorists can also benefit from an LWCMS through reduced travel times. By providing TxDOT with real-time information about the status of the low water crossings, an LWCMS will enable TxDOT maintenance workers to open roads in a timely manner when they are passable. This will save motorists the time they would otherwise have had to spend waiting for a road to open; also saved is the time spent driving an alternate route when the preferred route is actually passable. But because the exact amount of time saved by motorists during rainstorms is difficult to quantify, it was therefore not included in the model as a quantifiable benefit.

4.3 CALCULATING THE NET PRESENT WORTH

The next part of the RWIS Decision Support Tool involves calculating the net present worth (NPW) of implementing an RWIS. This step requires, first, determining the costs and benefits associated with implementing an RWIS over a 50-year life cycle, and then using these results to calculate the incremental net present worth of the system. The incremental net present worth of implementing an RWIS can then be compared to the "do nothing" alternative or to such other nonRWIS alternatives as building a structure in place of a low water crossing.

When calculating the incremental net present worth of an alternative, increased costs to the highway agency are expressed as negative values, while benefits to the public and reduced expenditures for the highway agency are expressed as positive values. For each alternative, the incremental net present worth is equal to the algebraic sum of capital costs and the discounted sum of annual savings and annual costs aggregated over 50 years.

The capital costs are the costs spent on RWIS hardware, software, and communications equipment, including installation. The annual costs consist of RWIS operating and maintenance costs and the costs for meteorological services. Part of the RWIS operating and maintenance costs will include the costs of replacing, repairing, and calibrating RWIS equipment. Capital costs and annual costs are calculated as described in sections 4.2.1.1 for ice detection applications and 4.2.2.1 for LWCMS.

The annual savings will derive from reductions in winter or storm maintenance costs and accident costs. RWIS savings in these areas are calculated directly as described in sections 4.2.1.2 and 4.2.1.3 for ice detection and 4.2.2.2 and 4.2.2.3 for LWCMS. A mathematical expression for the net present worth is written below.

$$NPW = -\text{(Capital Costs)} + [\text{(Annual Savings)} - \text{(Annual Costs)}] * (P/A, i, n)$$

$$NPW = -CC + [(S_M + S_A) - (O\&M + MS)] * (P/A, i, n)$$

where

NPW = Net Present Worth of alternative,
CC = Capital Costs,
S_M = Savings in winter/storm maintenance,
S_A = Savings from reduced accidents,
$O\&M$ = Operating and Maintenance Costs,
MS = Costs of Meteorological Services,
$(P/A, i, n)$ = Present value of aggregate series discount factor,
i = interest rate, and
n = number of years being aggregated = 50.

The formula for calculating the present worth of the aggregate series discount factor is expressed as follows when the aggregate series is uniform over the projects life cycle:

$$(P/A, i, n) = [(1+i)^n - 1] / [i(1+i)^n]$$

The interest rate used in this model should represent the minimum attractive rate of return for one year. Since the majority of the economic models reviewed in the literature used an interest rate of 5 percent, this model will also incorporate an interest rate of 5 percent when calculating the incremental net present value of various alternatives.

The incremental net present worth of implementing an RWIS can be compared against doing nothing or against the incremental net present worth of other alternatives. In the first case, the incremental net present worth of doing nothing is set equal to zero.

Therefore, a net present worth greater than zero for RWIS implementation would indicate that implementing an RWIS is a cost-effective alternative to doing nothing.

In the case of comparing the NPW of an RWIS versus the NPW of other alternatives, the NPW of the other alternative also needs to be calculated. This calculation will be performed as before, except all costs and savings will be the result of the alternative being considered instead of the RWIS implementation. For instance, if the other alternative was to build a structure in place of a low water crossing, then the NPW of this alternative would be calculated using the same NPW equation; there would, however, be no costs for meteorological services and the annual savings may be realized in different ways. In all cases, the final decision should be based on selecting the alternative having the highest NPW.

4.4 LOW WATER CROSSING REGRESSION MODEL

The RWIS Decision Support Tool also includes a low water crossing regression model to help determine which low water crossing sites within a district or county are most in need of RWIS implementation. This model can be used to rank the low water crossings by need for an LWCMS. From these rankings, a highway agency can prioritize the list of potential sites and then calculate the NPW for various alternatives in the manner described above. Thus, the regression model acts as a first cut to a large list of potential sites. This method will eliminate the need to calculate the NPW for a large number of alternatives, which can be a tedious process.

The low water crossing regression model was created from a database of low water crossings in Texas. The database is the result of a survey that was sent to 283 maintenance supervisors throughout Texas. The survey asked the supervisors to list all of the low water crossings within their area of responsibility and to provide some historical data for each site. These data included:

- distance from nearest maintenance office,
- AADT,
- number of flooding events in past five years,
- number of fatal accidents in past five years,
- number of injury accidents in past five years,
- number of property damage accidents in past five years, and
- which other crossings the site could be grouped with, if any.

Additionally, the survey asked the supervisor to assess the need for an RWIS at that site by giving the site a score from 1 to 5. The meaning of each of these scores is listed below.

- 1 = RWIS would be of no use
- 2 = RWIS would be of little use
- 3 = RWIS would be of some use
- 4 = RWIS would be very useful
- 5 = RWIS is absolutely essential

The results of the survey were entered into a low water crossing database and sorted by district and county. The database consists of 911 records from 123 different respondents. Over 600 of these records contain complete data. The records containing complete data were used to develop a multiple linear regression model that predicts the value of a LWCMS at any given site.

The following independent variables were included in the original model: distance, the natural logarithm of AADT (ln_AADT), the natural logarithm of storm frequency (ln_freq), fatal accidents, injury accidents, property damage accidents, and group. Of these variables, only ln_AADT, ln_freq, fatal accidents, and property damage accidents were found to be statistically significant ($p < .05$). Also, AADT and fatal accidents were found to have the strongest effect on the dependent variable. Several interaction variables, such as frequency multiplied by AADT and number of accidents multiplied by frequency and AADT, were introduced in later versions of the model but were ultimately omitted from the final model because they did not improve the model's R^2 score.

Since the variables "distance" and "group" were not found to be statistically significant, they were removed from the model. In order to incorporate injury accidents into the model, a new variable was created for nonfatal accidents. Nonfatal accidents were calculated by summing fatal accidents and property damage accidents. This variable was found to be statistically significant. Table 4.6 contains the relevant statistics for the low water crossing regression model.

Table 4.6 Low water crossing regression model statistics

Model: $R^2 = .28$

variable	parameter estimate	standard error	T	Prob > T
Intercept	.6986	.2525	2.767	.0058
ln_AADT	.3069	.0339	9.064	.0001
ln_freq	.1386	.0698	1.987	.0474
fatal	1.107	.3434	3.223	.0013
non-fatal	.0790	.0312	2.535	.0115

From Table 4.6 it is clear that all of the variables used in the final model are statistically significant, since their t-statistics are quite large and all of their corresponding p-values are less than .05. Unfortunately, the model has a somewhat low R^2 value of .28. The R^2 statistic is a value from 0 to 1 that measures the "goodness of fit" of the model. One reason for the low R^2 value is the fact that the type of data being predicted by the model is ordinal data or data that has predefined sequential values. In this case, the dependent variable "value" could only be an integer from 1 to 5 in the low water crossing database. This type of data is very difficult to predict using a multiple linear regression model.

Another possible reason for the low R^2 value could be that there were other variables influencing "value" that weren't accounted for in the survey. Examples of these variables may be whether the site was located on an emergency route, whether there was an alternate route, how quickly the site flooded, and the duration of flood events at the site. In any case, the model used by the RWIS Decision Support Tool still acts as a good tool for prioritizing which low water crossings are most in need of an LWCMS.

The final low water crossing regression model is expressed as:

$$\text{Value} = 0.6986 + [0.3069 * \ln(AADT)] + [0.1386 * \ln(frequency)] + [1.107 * fatal] + [0.0790 * non\text{-}fatal]$$

where

Value = value of an RWIS at the site (used for priority ranking of sites),

AADT = Annual Average Daily Traffic,

frequency = number of times the site has been flooded in past five years,

fatal = number of fatal accidents in past five years, and

non-fatal = number of non-fatal accidents in past five years.

To apply this model, a decision maker will need a list of low water crossing sites along with their associated values for each of the independent variables in the model. By plugging these values into the model, the decision maker will receive an estimated score for the "value" of an RWIS at each site. This "value" can also be viewed as the value that would probably be assessed by the collective judgment of over 100 maintenance supervisors in Texas. The actual value of implementing an LWCMS at any particular site will vary from this estimate. Table 4.7 demonstrates how the "value" predicted by the model may vary from the actual value given by the maintenance supervisor.

Table 4.7 Sample LWC regression model output

Site	AADT	freq	fatal	non-fatal	survey "value"	model "value"
SH 163 @ Juno Crossing	250	20	1	1	5	4.01
SH 163 @ Cull Crossing	250	12	0	0	1	2.74
SH 163 @ Pecos Crossing	110	12	0	0	1	2.49

The "value" predicted by the model, usually between 1 and 5, can then be used to rank the sites in order of RWIS need. Depending on the desired size of the first cut, any number of potential low water crossing sites can then be selected for further consideration based on their RWIS need ranking. After this initial selection process, the remaining sites can be analyzed using the NPW methodology mentioned in section 4.3 to determine which low water crossings, if any, will receive monitoring systems.

The number of sites receiving an RWIS will depend on the size of the district or county's RWIS budget. This selection process is very important in that it provides a documented procedure for determining which sites receive RWIS implementation under budgetary constraints. The use of the low water crossing regression model is demonstrated in Chapter 5.

4.5 LOW WATER CROSSING REGRESSION MODEL VERSUS NET PRESENT WORTH

In general, the rank order given by the low water crossing regression model will be similar to the rank order given by the net present worth procedure described in section 4.3. The major difference between the two procedures is that the regression model relies solely on historical data, such as past accidents and frequency of storm events, while the net present worth process is based more on probability and expected costs and savings. In general, the net present worth process is a more rigorous process and is generally more reliable; on the other hand, the regression model is a good tool for performing a quick prioritization for a large group of low water crossing sites.

4.6 APPLICATION OF RWIS DECISION SUPPORT TOOL

The RWIS Decision Support Tool can be used to make decisions for either a single site or for an entire area or district. The tool can also be used for applications involving either ice detection or flood monitoring. When making decisions about a single site, the decision maker should first calculate the NPW of each alternative. These alternatives will include the do-nothing alternative, implementing an RWIS at that site, and perhaps another alternative to implementing an RWIS (such as making a major improvement to the road or structure so that the problem will be eliminated). When calculating the NPW of each alternative, all factors that influence life-cycle costs need to be considered. Some methods for estimating costs and cost savings for both types of RWISs were given in section 4.2. In the end, whichever alternative has the largest NPW should be the solution that is chosen for that particular site.

When making decisions for an entire district or county, one needs to first consider their project budget. This is necessary to determine how many RWIS sites the agency wishes to implement and how sophisticated they want their RWIS sites to be. Once these have been determined, a list of potential RWIS sites must be gathered and analyzed. If the sites are low water crossings then the low water crossing regression model can be used to narrow down the number of sites. Once the list of potential sites has been narrowed down, the NPW model should be used in an aggregated form to determine the NPW of various combinations of RWIS sites. The calculated value of each NPW will be an aggregation of the costs and savings associated with implementing an RWIS at each given site within the area of responsibility. Once again, the alternative having the highest NPW should be the one that is chosen for the district or county. Chapters 5 and 6 describe case studies that illustrate the application of the RWIS Decision Support Tool.

CHAPTER 5. KERRVILLE CASE STUDY

This chapter describes how the RWIS Decision Support Tool can be applied to a real-world situation. For this purpose, Kerrville will be used as a case study. The RWIS Decision Support Tool will be used to first select a site for LWCMS implementation, and then to perform a life-cycle cost analysis on implementing a low water crossing monitoring system at the site. Next, a life-cycle cost analysis will be performed on building a bridge at the site as an alternative to implementing an LWCMS. After this, the net present value of the LWCMS can be compared with the net present worth of the bridge alternative and the "do nothing" alternative.

5.1 BACKGROUND

The TxDOT maintenance office in Kerrville is responsible for 64 low water crossings located throughout Kerr County. Some of these crossings are located as far as 96.5 km (60 miles) away from the nearest maintenance office; in addition, a number of these crossings experience frequent flooding during rainstorms. At times, the intensity of the flooding is such as to be capable of washing away motorists attempting to drive across the low water crossings. These incidents can result in property damage, injury, or even death.

In the early 1990s the Upper Guadalupe River Authority (UGRA) purchased for approximately $225,000 a flood warning system from Remote Operating Systems. The Kerrville Fire Department and the TxDOT Maintenance Office in Kerrville also use this flood warning system. The system consists of 22 remote sites equipped with rain gauges and 11 sites equipped with water-level sensors. The rain gauges and level sensors are connected to solar-powered RPUs at each site. Each RPU reports readings back to a CPU in the maintenance office via FM radio. The CPU is equipped with an ROS-developed Wonderware software package to monitor the sensor data.

The TxDOT maintenance office in Kerrville uses the system to predict when roadways and low water crossings may become flooded. By knowing the rate of rainfall at specific high locations, the maintenance supervisor can predict where the rain will run off and which roads and crossings are in danger of becoming flooded. The system also alerts the maintenance office when the floodwater has reached a level that is above the road surface at a site monitored by a continuous level sensor. Currently, none of these sites use the level readings to activate message signs to warn motorists of road conditions.

TxDOT is implementing a new low water crossing monitoring system at a site in Kerr County. The new LWCMS will be tied into the already existing ROS flood warning system. The system will consist of a level sensor installed in a stream crossing hardwired to a solar-powered RPU on the side of the road. The level sensor will take continuous readings of the water level at the crossing. This information will be sent via radio from the RPU to the CPU where the data may be viewed. The LWCMS will also have solar-powered message signs equipped with flashing lights at each end of the crossing to warn motorists of potentially dangerous road conditions. The flashing lights will be activated when the level sensor detects water above the road surface. Figure 5.1 shows the level sensor while Figure 5.2 shows the message sign installed at the LWCMS in Kerrville.

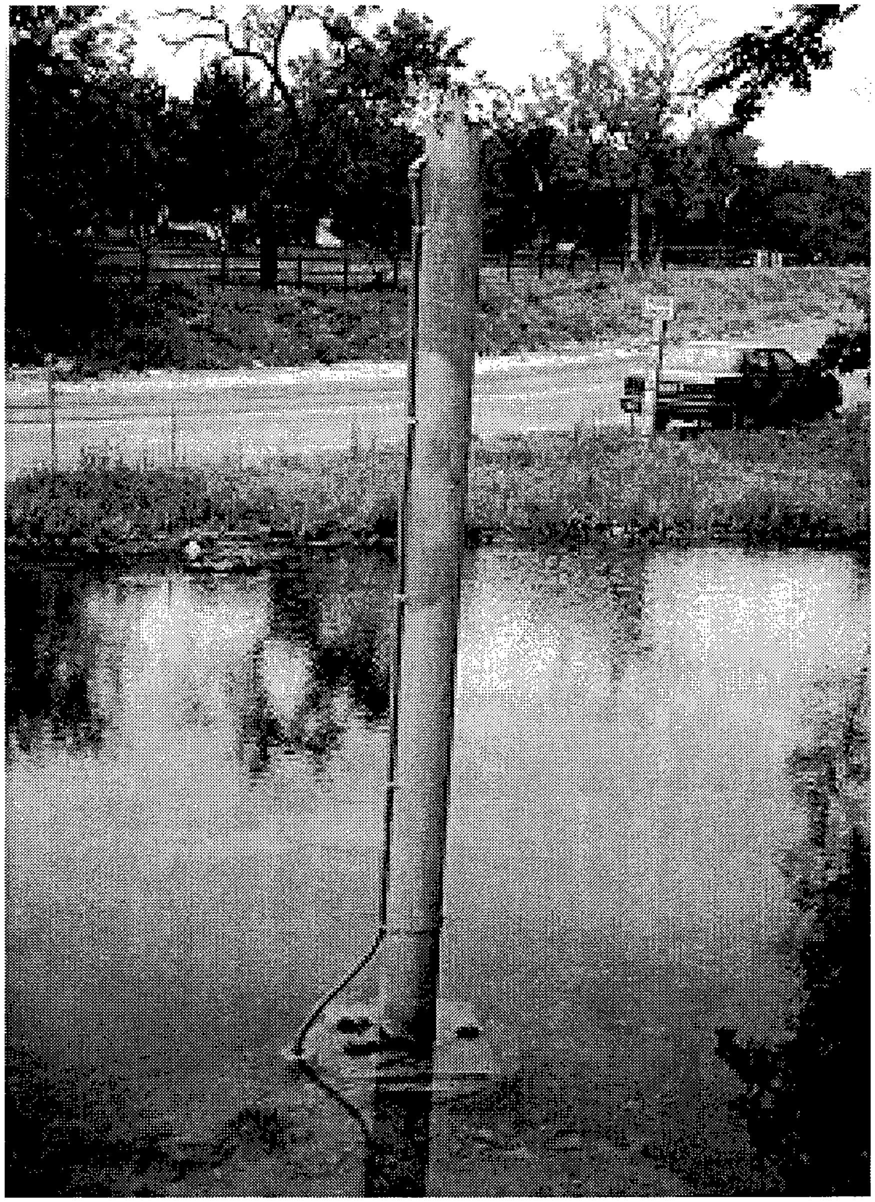

Figure 5.1 Level sensor installed in Kerrville

Figure 5.2 Flashing message sign installed in Kerrville

5.2 MODEL INPUTS

There are a number of low water crossing sites in Kerr County that could be considered candidates for LWCMS implementation. The TxDOT maintenance office in Kerrville provided a list of eight potential sites. This list includes the eight sites that are most in need of an LWCMS, as determined by TxDOT. This list of sites and their associated characteristics and five-year historical data are included in Table 5.1.

Table 5.1 Potential LWCMS Sites in Kerr County

Site	AADT	Freq (5 yrs)	Fatal (5yrs)	Injury (5 yrs)	PD (5 yrs)
FM 1338 @ 1st Goat Creek Crossing	1500	35	0	0	3
FM 1338 @ 2nd Goat Creek Crossing	1250	30	0	0	1
SH 16 @ Turtle Creek	570	25	0	0	0
FM 1340 @ Waltamer	110	20	1	0	0
FM 2771 @ 1st Paris Crossing	320	15	0	0	0
FM 2771 @ 2nd Paris Crossing	320	15	0	0	0
FM 1273 @ HEB Crossing	480	10	0	0	0
FM 1340 @ Wagon Wheel	110	12	0	0	0

Besides a listing of potential sites and their associated characteristics and historical data, there are other input data that need to be collected, including storm maintenance procedures, budgetary constraints, and site groupings. These data are described below.

The TxDOT maintenance office in Kerrville currently operates six maintenance crews (two workers per crew) during severe rainstorms. These crews are responsible for patrolling the roads in Kerr County to check for flooded conditions, and to open and close roads according to whether they are passable. For some of the roads, such as FM 1338, there is no alternate route for the residents living in that area. Therefore, a maintenance crew is required to patrol the low water crossings on that road every hour or so to check if the road is flooded. A maintenance crew must also open or close the road using a barricade so that the residents of the area will not try to cross a flooded site.

The TxDOT maintenance office in Kerr County has budgeted about $15,000 for acquiring an LWCMS, with part of the expenditure being subsidized by this research project. This amount does not include operations and maintenance costs. Owing to the budget's limitations, only one LWCMS will be implemented at this time.

There are two groupings from our list of potential sites. The first group includes the Goat Creek crossings on FM 1338, of which the first Goat Creek crossing is to be monitored. The second group includes the Paris crossings on FM 2771, of which the first Paris crossing is to be monitored.

5.3 PRIORITIZATION OF SITES

The eight low water crossings in Kerr County were prioritized using the low water crossing regression model presented in section 4.4. The model outputs and a ranking of the sites are presented in Table 5.2.

Table 5.2 Priority ranking of sites

Rank	Site	Value (model output)
1	FM 1338 @ first Goat Creek crossing *	3.68
2	FM 1340 @ Waltamer	3.66
3	FM 1338 @ second Goat Creek crossing *	3.44
4	SH 16 @ Turtle Creek	3.09
5	FM 1273 @ HEB crossing	2.91
6	FM 2771 @ first Paris crossing **	2.85
7	FM 2771 @ second Paris crossing **	2.85
8	FM 1340 @ Wagon Wheel	2.49

* The first and second Goat Creek crossings can be grouped together.

** The first and second Paris crossings can be grouped together.

From the results obtained through the low water crossing regression model, we can now reduce the size of our list of potential sites by eliminating the sites having the lowest need rankings, since we know that these sites will likely have a lower net present worth. For this particular case study, we will make a "first cut" that eliminates all but one site, given that our RWIS budget allows for only one LWCMS installation.

Of the top sites, there are two sites that can be grouped together, namely, the two sites on FM 1338; they are ranked first and third on the priority list. Since we can accommodate both of these sites with just one LWCMS, we can expect that our return on investment from an LWCMS implemented at these two sites will be greater than that from any one of the other sites. Therefore, we will choose the two sites on FM 1338 as our LWCMS implementation sites. The first Goat Creek crossing, shown in Figure 5.3, will be the site to be monitored, since it is the site that floods the most frequently. Figure 5.4 shows a plan view of the two crossings and the flashing message signs on FM 1338. The next step in the RWIS Decision Tool is to calculate the net present worth of the Kerrville LWCMS to determine if it is a prudent investment.

Figure 5.3 First Goat Creek crossing on FM 1338 in Kerr County

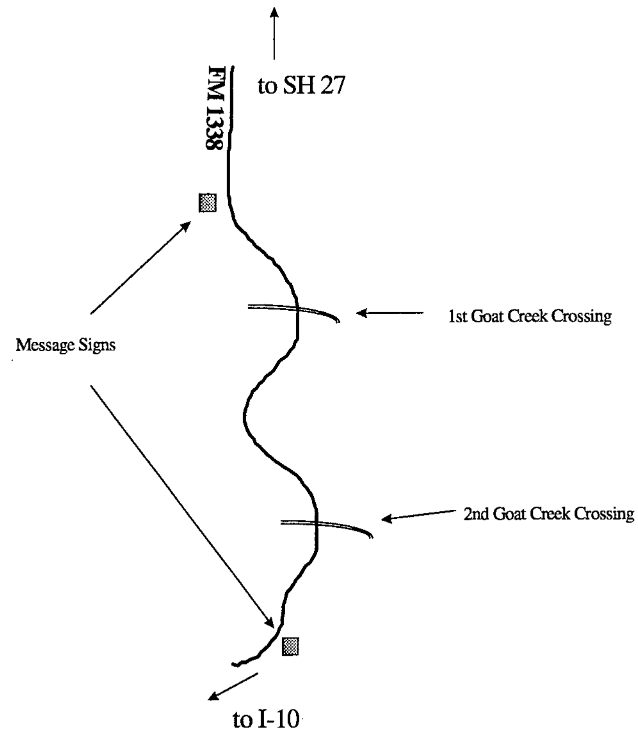

Figure 5.4 Plan view of FM 1338 and Goat Creek crossings

5.4 LIFE-CYCLE COST ANALYSIS OF AN LWCMS

This section analyzes the life-cycle cost of implementing an LWCMS on FM 1338 in Kerrville. The life-cycle cost analysis will first estimate the costs and benefits associated with implementing an LWCMS over a 50-year life cycle, and will then use these results to calculate the incremental net present worth of the LWCMS alternative. The incremental net present worth of implementing an LWCMS can then be compared with the net present worth of building a bridge or of doing nothing, in order to determine which alternative is economically justifiable.

5.4.1 Direct Costs for an LWCMS

Direct costs include the capital costs and annual costs that are directly associated with a low water crossing monitoring system. The capital costs for the FM 1338 LWCMS were acquired directly from the vendor's proposal. These costs are for three RPUs (one at the crossing and one at each message sign), solar power and data radios at each RPU, one level sensor, installation, and system testing. The message signs and labor were provided by TxDOT and are not included in the capital costs. The capital costs are detailed in Table 5.3.

Table 5.3 Capital costs for Kerrville installation

Description	No.	Item Cost	Expanded Cost
RPU	3	$1,265.00	$3,795.00
RPU Enclosure	3	$234.00	$702.00
RPU Back Plates	3	$34.00	$102.00
Solar Chargers	3	$85.00	$255.00
33 Amphr Batteries	3	$112.00	$336.00
7 Watt Solar Panel (for message signs)	2	$166.67	$333.34
20 Watt Solar Panel (for RPU at site)	1	$376.67	$376.67
Radio	3	$446.67	$1340.01
Antenna Kit	3	$222.22	$666.66
1.8 m (6 ft) Level Sensor	1	$970.00	$970.00
1.8 m (6 ft) Galvanized Housing	1	$270.00	$270.00
Software Installation and System Testing	1	$600.00	$600.00
CPU (w/software)	1	$3000.00	$3,000.00
Site Survey	1	$450.00	$450.00
Total Capital Cost			**$13,197**

For a 50-year project life cycle, these capital costs will need to reinvested every 25 years, since the LWCMS life cycle is only 25 years. Therefore, there will be a $13,197 investment in year 1997 and year 2022. Also, since the RPUs and the CPU will need to be upgraded every five years in order to keep up with new technology, there will be a $6,795 upgrade cost every fifth year starting in the year 2002 and ending in the year 2042.

The annual costs include operations and maintenance costs, as well as the costs for meteorological services. For this installation, there will be no additional meteorological services, so annual costs will include only operations and maintenance costs. These costs can be estimated using Equation 4.20. Since this installation uses radio communication, there will be no long distance phone charges. The estimated annual operations and maintenance costs for the Kerrville installation are calculated below.

Annual O&M Costs = [5% * (Total Capital Costs)] = 5% * $13,197 = $\underline{\$660}$

5.4.2 Indirect Cost Savings for an LWCMS

As mentioned in section 4.2.2.2, the main area of indirect savings will be through reduced patrolling and road maintenance during rainstorms. Since the maintenance supervisor in Kerrville will be provided with real-time information about the status of the FM 1338 low water crossings from the LWCMS, he will not need to send maintenance crews out to that site unless a problem has been reported. This eliminates the need to patrol that site and allows the TxDOT maintenance crews in Kerrville to spend their time more efficiently on sites that need their attention.

In the case of the FM 1338 site, there is no alternate route for the residents in that area; consequently, the site requires attention. A maintenance crew is required to patrol the site every hour or so to check if the road is flooded. With the installation of an LWCMS, this information will be available to the maintenance supervisor at the maintenance office, and to travelers via the message signs. Such information will free up maintenance crews to concentrate their patrolling on other areas — thus allowing the Kerrville Maintenance section to operate more efficiently. We assume that the site on FM 1338 required approximately four hours per storm to patrol. This is half of a normal eight-hour patrol shift. Patrol savings can be quantified using Equations 4.1 and 4.21 and the unit costs from Table 4.2.

Cost/patrol shift = 8hrs * [(2 * $25.50/hr) + $24/hr (truck cost)] = <u>$600</u>
Annual Patrol Savings = (0.5 patrol shifts/storm) * (7 storms/year) * ($600/crew) = <u>$2,100</u>

Given that this is the only quantifiable area of indirect savings associated with the implementation of an LWCMS, the total indirect savings from the implementation of an LWCMS on FM 1338 in Kerr County is:

S_m = Annual Savings from reduced storm maintenance costs = <u>$2,100</u>

5.4.3 Social Cost Savings for LWCMS

The primary manner in which the Kerrville LWCMS will result in social cost savings is by reducing the number of automobile accidents that occur on FM 1338 when the Goat Creek crossings are flooded. The social cost savings resulting from the LWCMS implementation can be estimated by taking the standard cost for each type of accident from Table 4.3 and multiplying that cost by the expected reduction of those types of accidents on FM 1338. Using the methodology described in section 4.2.2.3, we were able to derive a simplified equation for the annual accident savings associated with LWCMS implementation. This equation was expressed as follows.

$$S_A = 13.2 * AADT * Freq * PF * OF \qquad (4.31)$$

where

AADT = Average Annual Daily Traffic (veh/day),

Freq = Frequency of Flooding Events (events/year),

PF = Preventable factor (percentage of accidents that could be prevented with warning system), and

OF = Obedience factor (likelihood that a motorist will heed warning).

Because the TxDOT maintenance supervisor in Kerrville estimates that 50 percent of the low-water-crossing accidents in Kerr County are the result of motorists not receiving adequate warning about flood conditions, ***PF*** will be 0.5 for this application. The Kerrville maintenance supervisor also estimates that the likelihood that a motorist will obey a flood warning when one is provided is 0.9. Therefore, ***OF*** will be 0.9 in this application.

Also, from Table 5.1 we know that the AADT and annual storm frequency for the first Goat Creek crossing are 1500 and 7; for the second Goat Creek crossing they are 1250 and 6. Since the two crossings are interdependent and located so close to each other, we should only count the vehicles the first time they reach one of the crossings. In other words, we will count only the traffic entering the first crossing from the SH 27 side and the traffic entering the second crossing from the I-10 side (see Figure 5.4). Thus, the AADT will be reduced by half for both crossings. When we input these data into Equation 4.31, we can compute annual accident savings as follows for the two Goat Creek crossings.

Annual Accident Savings for FM 1338 at the first Goat Creek crossing:

$$S_A = 13.2 * (1500/2) * 7 * 0.5 * 0.9 = \underline{\$31{,}000}$$

Annual Accident Savings for FM 1338 at the second Goat Creek crossing:

$$S_A = 13.2 * (1250/2) * 6 * 0.5 * 0.9 = \underline{\$22{,}000}$$

Annual Accident Savings for both sites combined:

$$S_A = \$31{,}000 + \$22{,}000 = \underline{\$53{,}000}$$

5.4.4 Net present Worth of LWCMS

This section will calculate the net present worth of implementing an LWCMS on FM 1338 in Kerrville. The capital costs and annual costs associated with this alternative are summarized in Table 5.4. Figure 5.5 is a cash flow diagram that shows how these costs and savings are incurred over time.

Table 5.4 Summary of costs and savings for Kerrville LWCMS

Cost Category	Amount
Capital Costs (total system)	$13,197 (every 25 years)
Capital Costs (RPU & CPU upgrades)	$6795 (every 5 years)
O&M Costs	$660 per year
Costs of Meteorological Services	$0 per year
Storm Maintenance Savings	$2,100 per year
Accident Savings	$53,000 per year

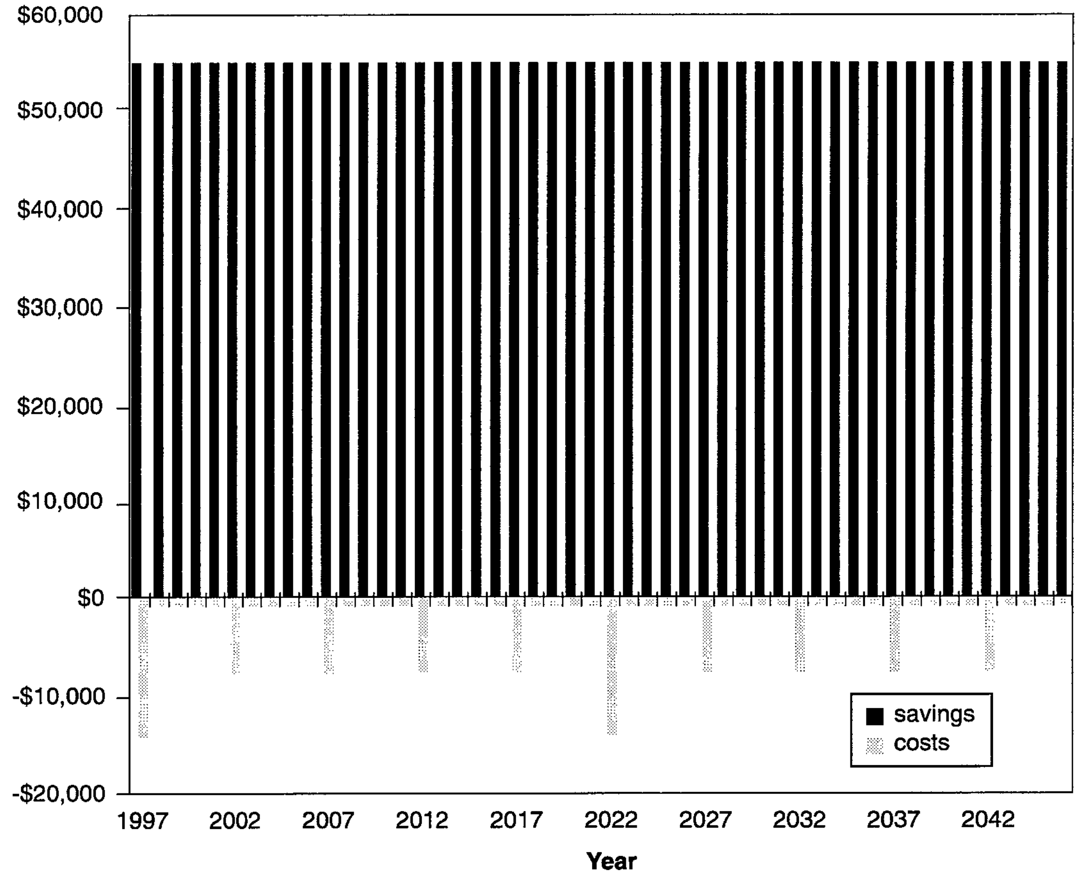

Figure 5.5 Cash flow diagram for Kerrville installation

As mentioned in section 4.3, the mathematical expression for the net present worth is written as follows.

NPW = - (Capital Costs) + [(Annual Savings) - (Annual Costs)] * (P/A, i, n)

NPW = $- CC + [(S_M + S_A) - (O\&M + MS)] * (P/A, i, n)$

where

NPW = Net Present Worth of alternative,

CC = Capital Costs,

S_M = Savings in winter/storm maintenance,

S_A = Savings from reduced accidents,

O&M = Operating and Maintenance costs,

MS = Costs of Meteorological Services,

(P/A, i, n) = Present value of aggregate series discount factor,

i = discount rate = 5%, and

n = number of years being aggregated = 50.

When we substitute the values associated with our Kerrville LWCMS, we get the following result:

$$NPW = -(\$13,197) + [(\$2,100 + \$53,000) - (\$660)] * (P/A, 5\%, 50)$$

$$NPW = -(\$13,197) + (\$54,440) * (P/A, 5\%, 50)$$

The formula for calculating the present worth of aggregate series discount factor for an interest rate of 5 percent and a life cycle of 50 years is written below.

$$(P/A, 5\%, 50) = [(1 + .05)^{50} - 1] / [.05 (1 + .05)^{50}] = \underline{18.26}$$

When calculating the net present worth of the system, we must also remember to factor in the reinvestment cost of $13,197 after 25 years, as well as the RPU and CPU upgrade costs of $6795 every five years. These costs will need to be discounted using the following discount factor for present worth of a future payment.

$$(P/F, 5\%, 50) = 1 / (1 + .05)^{n}$$

where $\boldsymbol{n}$ = number of years until future payment.

These discounted costs are then subtracted from the previous ***NPW*** formula. Thus, the incremental net present worth of implementing an LWCMS in Kerrville is calculated as follows (rounding the result to the nearest thousand dollars):

$$\begin{aligned} NPW = & - (\$13,197) + (\$54,440 * 18.26) - (\$13,197 * .295) - (\$6,795 * .784) \\ & - (\$6,795 * .614) - (\$6,795 * .481) - (\$6,795 * .377) - (\$6,795 * .295) \\ & - (\$6,795 * .231) - (\$6,795 * .181) - (\$6,795 * .142) - (\$6,795 * .111) \\ & = \underline{\$955,000} \end{aligned}$$

It should be noted that the majority of the contribution to the net present worth of this system comes from annual accident savings, which amount to $53,000. This may seem like a very high amount, but the amount is justifiable. One way of understanding this is by looking at a hypothetical situation. Suppose the implementation of this system saves one human life over the next 50 years. This is equivalent to a social savings of $1,700,000 (without using the discount factor), which is easily enough to justify the cost of the system.

5.5 LIFE-CYCLE COST ANALYSIS OF BUILDING A BRIDGE

The next step of the RWIS Decision Support Tool is to perform a life-cycle cost analysis on building two bridge structures on FM 1338 in Kerrville. The life-cycle cost analysis will first estimate the costs and benefits associated with building the bridges for a 50-year life cycle, and then use these results to calculate the incremental net present worth of the bridge alternative. The incremental net present worth of building the bridges can then be compared with the net present worth of implementing an LWCMS, which was calculated in the previous section, and with the "do nothing" alternative, in order to determine which alternative is economically justifiable.

5.5.1 Direct Costs for Bridge Alternative

The two bridges would be constructed over the first and second Goat Creek crossings on FM 1338. Each crossing would require a sectional span bridge to be constructed — one that would not create a damning effect on Goat Creek (given its proximity to a number of homes).

The capital costs associated with building a sectional span bridge on FM 1338 were estimated at $650,000 by the TxDOT maintenance office in Kerrville. In addition to capital costs, TxDOT anticipates incurring maintenance costs every 10 years. After the first 10 years, maintenance costs were estimated to be 1 percent of the total capital costs ($6,500). Every 10 years thereafter, the maintenance costs were estimated to be 2 percent of the total capital costs ($13,000). The capital and maintenance costs for two bridges will simply be double the costs for one bridge.

5.5.2 Indirect Cost Savings for Bridge Alternative

The storm maintenance savings associated with sectional span bridges at the two Goat Creek crossings will be equivalent to those for the LWCMS alternative, since no patrolling will be necessary during storms. Thus, the annual patrol savings and storm maintenance savings for the bridge alternative are calculated as follows:

Annual Patrol Savings = (0.5 patrol shifts/storm) * (7 storms/year)* ($600/crew) = $\underline{\$2{,}100}$

$$S_m = \text{Annual Savings from reduced storm maintenance costs} = \underline{\$2{,}100}$$

5.5.3 Social Cost Savings for Bridge Alternative

The accident savings associated with the bridge alternative can be calculated as follows. Referring to Equation 4.22, the expected annual number of accidents occurring at flooded low water crossings is equal to the product of site exposure and accident rates. This relationship is expressed below.

$$E(A_i) = \text{Site Exposure} * AR_i \tag{4.22}$$

where

$E(A_i)$ = expected # of accidents of type i during flooded conditions (acc/year),

Site Exposure = # of vehicles crossing site during flooded conditions (veh/year), and

AR_i = Accident Rate for type i accident at site during flooded conditions (acc/veh).

The next step in our process is to estimate how many of these expected accidents will be reduced when the bridge structures are built on FM 1338. Since the bridges would be constructed to handle a 100-year flood event, we can anticipate a 100 percent reduction in expected accidents. Thus, the number of accidents that can be reduced by having the bridges constructed will be the same as the expected number of accidents. This is represented in the following equation:

$$R(A_i) = \text{Site Exposure} * AR_i$$

$R(A_i)$ = expected # of reduced accidents of type i each year (acc/year).

Site Exposure can be calculated by multiplying the AADT of the site by the frequency of flooding at the site by the length of time the site remains flooded each event (four hours). From Equation 4.26, this was expressed as follows:

$$\text{Site Exposure} = AADT * Freq * 1/6 \tag{4.26}$$

where

AADT = Average Annual Daily Traffic (veh/day), and

Freq = Frequency of Flooding Events (floods/year).

Using the accident rates from Table 4.5 and Equations 4.22 and 4.26, we can now compute estimates for the expected number of reduced fatal, injury, and property damage accidents that result from constructing bridges for the two Goat Creek crossings on FM 1338. Using these estimates and the accident costs from Table 4.3, we can calculate an estimate for accident savings associated with the bridge alternative. The expected annual accident savings for both crossings are listed below.

Annual Accident Savings for FM 1338 at the first Goat Creek crossing:

$$S_A = \underline{\$69{,}000}$$

Annual Accident Savings for FM 1338 at the second Goat Creek crossing:

$$S_A = \underline{\$50{,}000}$$

Annual Accident Savings for both sites combined:

$$S_A = \$69{,}000 + \$50{,}000 = \underline{\$119{,}000}$$

5.5.4 Net present Worth of Bridge Alternative

This section will calculate the net present worth of building a bridge on FM 1338 in Kerrville. The costs and savings associated with the bridge alternative for FM 1338 are summarized in Table 5.5. A cash flow diagram is given in Figure 5.6 to show how these costs and savings are incurred over time.

Table 5.5 Summary of costs and savings for bridge alternative

Cost Category	Amount
Capital Costs (2 sectional span bridges)	$1,300,000 (50-year life)
O&M Costs (2 bridges) after 10th year after 20th, 30th, and 40th years	 $13,000 $26,000
Storm Maintenance Savings	$2,100 per year
Accident Savings	$119,000 per year

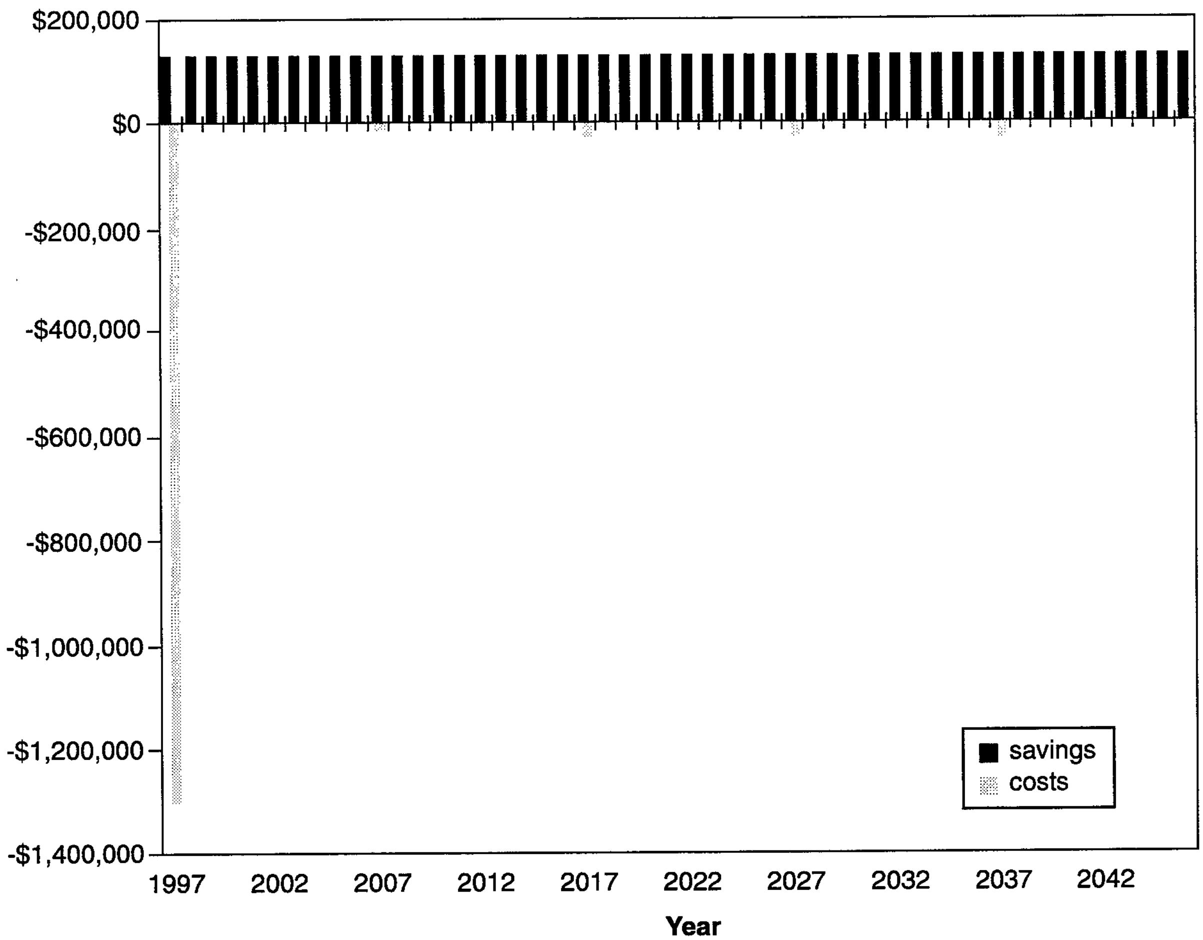

Figure 5.6 Cash flow diagram for bridge alternative

As mentioned in section 4.3, the mathematical expression for the net present worth is written as follows.

$$NPW = -(\text{Capital Costs}) + [(\text{Annual Savings}) - (\text{Annual Costs})] * (P/A, i, n)$$

$$NPW = -CC + [(S_M + S_A) - (O\&M + MS)] * (P/A, i, n)$$

where

NPW	=	Net Present Worth of alternative,
CC	=	Capital Costs,
S_M	=	Savings in winter/storm maintenance,
S_A	=	Savings from reduced accidents,
O&M	=	Operating and Maintenance costs,
MS	=	Costs of Meteorological Services,
(P/A, i, n)	=	Present value of aggregate series discount factor,
I	=	discount rate = 5%, and
n	=	number of years being aggregated = 50.

When we substitute the values associated with our bridge alternative, we get the following result rounded to the nearest thousand dollars:

$$NPW = -(\$1{,}300{,}000) + (\$121{,}100 * 18.26) - (\$13{,}000 * .614) - (\$26{,}000 * .377) - (\$26{,}000 * .231) - (\$26{,}000 * .142) = \underline{\$884{,}000}$$

5.6 ANALYSIS OF KERRVILLE CASE STUDY

This section analyzes the Kerrville case study results. The first part of the analysis compares the net present worth of the LWCMS with the net present worth of the bridge alternative and the "do nothing" alternative. Next, the analysis presents other benefits of the LWCMS that were not accounted for in the model.

5.6.1 Comparison of Alternatives

The RWIS Decision Support Tool was applied to the Kerrville TxDOT maintenance section to evaluate low water crossing monitoring alternatives. The Decision Tool determined that the site on FM 1338 at Goat Creek crossing was the highest priority for a low water crossing monitoring system. In the next step of the process, the RWIS Decision Tool estimated the net present value of a system installed at this site to be $955,000 over a 50-year life cycle. This net present worth can now be compared against the net present worth of other alternatives.

In the case of the "do nothing" alternative, the incremental net present worth of doing nothing is set equal to zero. Therefore, since the net present worth of implementing the LWCMS is $955,000, which is greater than zero, this would indicate that implementing an LWCMS on FM 1338 in Kerrville is a cost-effective alternative to doing nothing.

The incremental net present worth of implementing an LWCMS on FM 1338 can also be compared against the net present worth of replacing the two low water crossings with structures. In section 5.6, the costs and benefits associated with building two structures on FM 1338 were quantified and the net present worth of this alternative was estimated at $884,000. Since the net present worth of an LWCMS ($955,000) is slightly greater than that of the bridge alternative ($884,000), this would indicate that implementing an LWCMS for the two Goat Creek crossings on FM 1338 would be a slightly more cost effective solution than building two bridges. The LWCMS alternative has a slightly higher NPW in this particular case because two closely proximate and interdependent crossings were covered; however, if there were only one crossing on FM 1338, then the capital and maintenance costs for the bridge alternative would be halved, making it the more attractive alternative.

For low water crossings characterized by high AADTs, high storm frequencies, and low *preventable factors* (less than 50 percent), the bridge alternative will be a more attractive solution. On the other hand, for low water crossings with lower AADTs, lower storm frequencies and higher *preventable factors*, the LWCMS may be the best solution. When AADTs and storm frequencies are very low, however, the "do nothing" alternative will probably be the most cost-effective solution. The cut-off points for each of these parameters will vary from case to case, thus requiring the calculation of the net present worth of each alternative for each given situation.

5.6.2 Other Benefits of Kerrville LWCMS

There are a number of other benefits associated with the Kerrville LWCMS that were not accounted for in the calculation of its net present worth. First of all, there is the issue of liability. As mentioned earlier in this report, the City of San Antonio was held liable in an $8 million civil suit a few years ago when a woman, driving a vehicle, drowned at a flooded low water crossing. The jury found the City of San Antonio liable for not providing the woman fair warning about the dangerous crossing. By reducing the risk of accidents at low water crossings, and by providing motorists with real-time information about water level conditions, an LWCMS can reduce the likelihood that a lawsuit like this will be brought against TxDOT.

Another benefit of the Kerrville LWCMS is travel-time savings to motorists. By providing TxDOT with real-time information about the status of the low water crossings on FM 1338, the LWCMS will allow TxDOT maintenance workers to open FM 1338 as soon as it is passable. This will save motorists the time they would have had to spend in waiting for the road to be opened or in driving an alternate route even though the road may have been passable.

Finally, the Kerrville Fire Department will also benefit from the LWCMS through improved emergency response times. By knowing the status of low water crossings on FM 1338, the Kerrville Fire Department will be able make decisions as to which routes are the best to take when dispatching emergency vehicles. This improved emergency response time can be essential in saving lives.

CHAPTER 6. ABILENE CASE STUDY

This chapter describes another case study — this time in Abilene — to again demonstrate the application of the RWIS Decision Support Tool to a real-world situation. The RWIS Decision Support Tool will be used to perform a life-cycle cost analysis on the proposed bridge ice detection system in Abilene. If the net present value of this system is greater than zero, then the decision to implement the system will be justified. This chapter describes each step of the RWIS Decision Support Tool, including the estimation of direct costs, indirect cost savings, and social cost savings; a calculation of the net present worth of the system is also presented.

6.1 BACKGROUND

TxDOT is implementing a bridge ice detection system at the intersection of Interstate 20 and milepost 260, just west of Abilene, Texas. The system will consist of two pavement sensors embedded in the westbound lane of Intestate 20. One of the sensors will be installed in the bridge deck, while the other will be installed in the approach. Figure 6.1 shows how the pavement sensor is embedded in the bridge deck. A suite of atmospheric sensors will be installed next to the roadway on the RPU tower to gather other pertinent weather data, such as air temperature, humidity, wind speed and direction, and whether there is precipitation falling. Both the pavement sensors and the atmospherics will be hardwired to an RPU, which will relay the RWIS data via phonelines to a CPU in the Abilene maintenance office. Figure 6.2 shows the RPU tower with atmospherics.

This specific site was chosen because it freezes frequently and because it is located in an area that is representative of the weather conditions in Abilene. The RWIS information gathered at the site will be used to forecast pavement conditions on Interstate 20 for up to 24 hours in advance. This information will benefit the Abilene maintenance office staff by allowing them to schedule their winter maintenance activities more efficiently. The system will also benefit the traveling public in that it will help TxDOT reduce the amount of time that drivers are exposed to snowy or icy conditions, which should also reduce the number accidents on Interstate 20.

6.2 MODEL INPUTS

As mentioned above, the bridge site on Interstate 20 at milepost 260 was chosen for RWIS implementation because it freezes frequently and because it is situated in a locale that is representative of the weather conditions in the Abilene area. The annual average daily traffic at this site is 14,800; the site experiences approximately five storm events per year, with the average duration of each storm event being 48 hours.

The current winter maintenance procedures for the site area are as follows. For each storm event, there are two maintenance crews responsible for plowing snow and applying de-icing chemicals throughout the site area. Each maintenance crew is comprised of two workers and one truck. The two crews are continuously on duty throughout the 48-hour storm event. Their truck route spans three counties and covers a total of 80.4 centerline km

(50 centerline miles) of Interstate 20. Each storm event currently requires eight passes per truck, equaling 16 truckloads of de-icing material per storm. Each truckload contains 7.65 cubic meters (10 cubic yards) of sand, 0.91 metric tons (1 ton) of salt, and 0.45 metric tons (one-half ton) of magnesium chloride. The costs for these materials are $8 per 0.76 cubic meter (1 cubic yard), $60 per 0.91 metric tons (1 ton), and $400 per 0.91 metric tons (1 ton), respectively [Lauren Garduno, Maintenance Engineer, TxDOT Abilene, phone interview, 26 February 1997]. Also, during a typical 48-hour winter storm event, the TxDOT maintenance office in Abilene spends about 16 hours (two shifts) patrolling the 80.47-km (50-mile) section of Interstate 20.

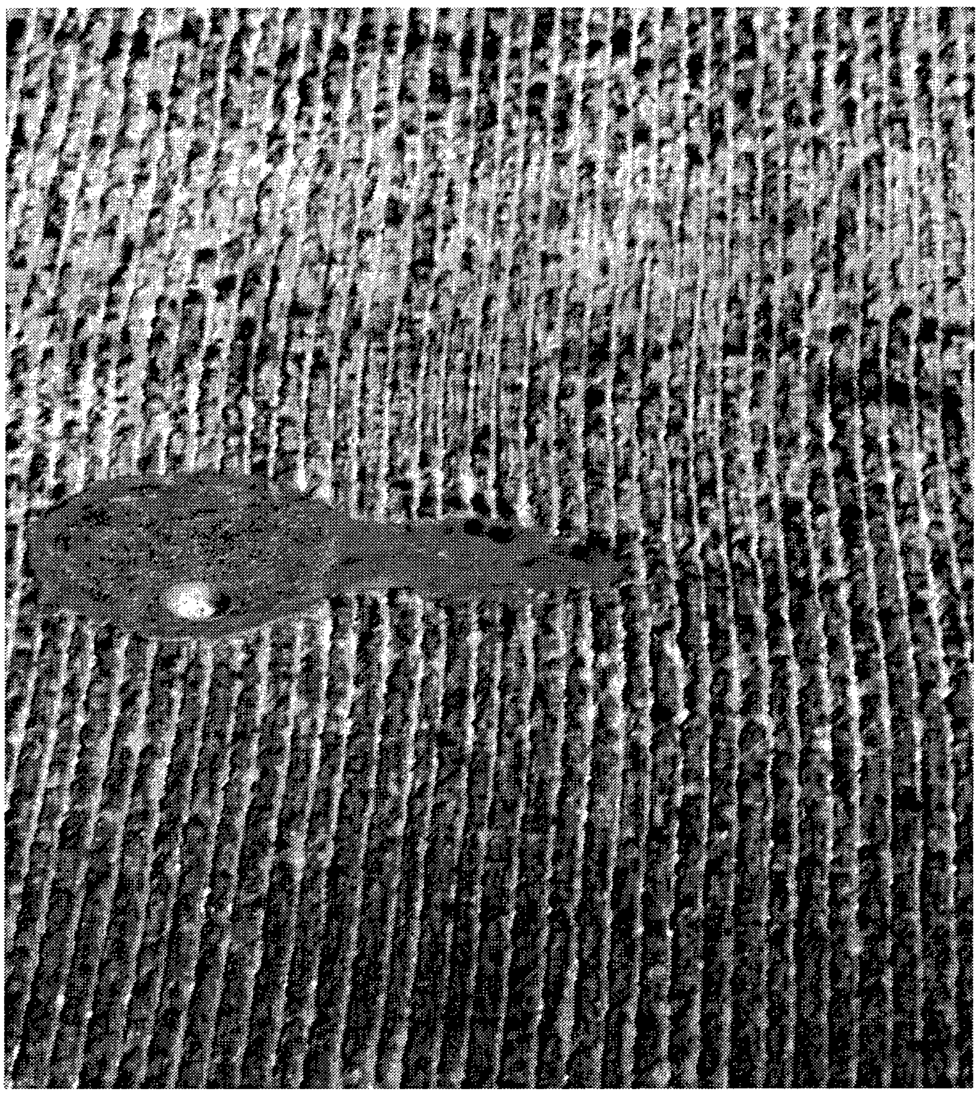

Figure 6.1 Pavement sensor embedded in bridge deck

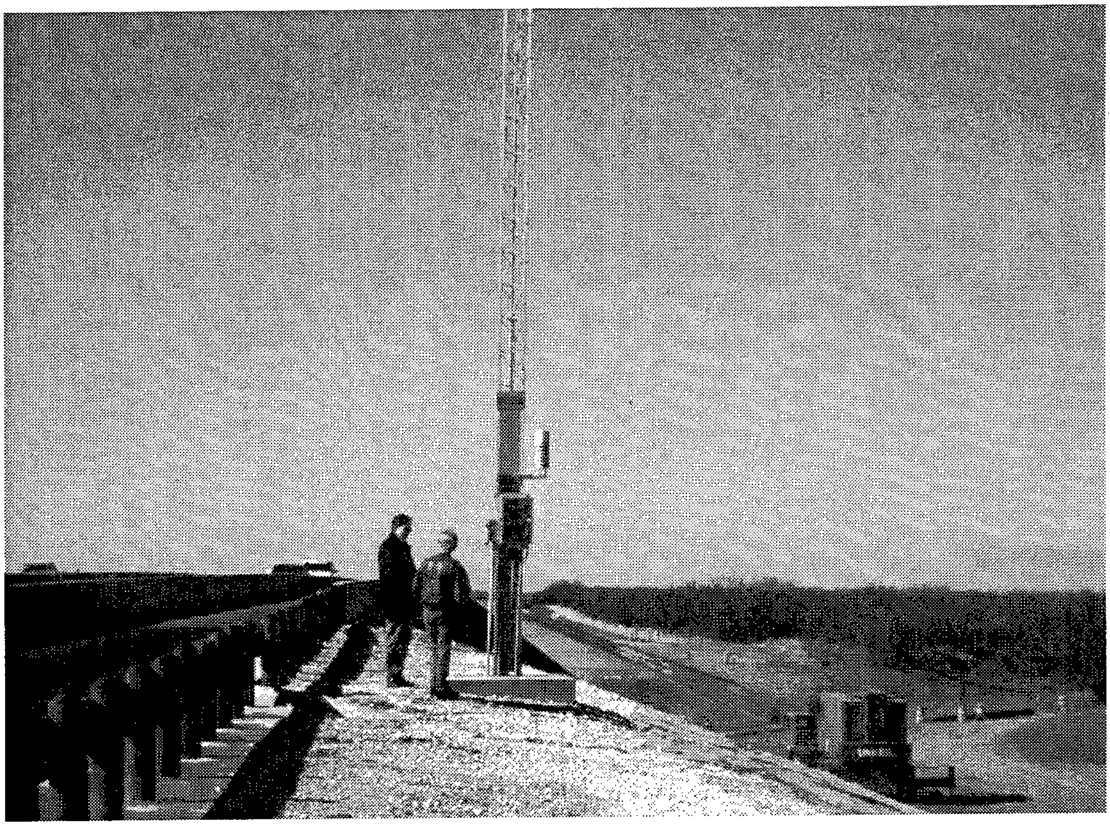

Figure 6.2 RPU tower with atmospherics

6.3 LIFE-CYCLE COST ANALYSIS FOR ABILENE RWIS

The next step in the application of the RWIS Decision Support Tool is to analyze the life-cycle cost of implementing a bridge ice detection system on Interstate 20 near Abilene. The life-cycle cost analysis will first determine the costs and benefits associated with implementing an RWIS over a 50-year life cycle, and will then use these results to calculate the incremental net present worth of the system. The incremental net present worth of implementing the RWIS can then be compared with the "do nothing" alternative to determine if it is economically justifiable to implement the system.

6.3.1 Direct Costs for RWIS

Direct costs include the capital costs and annual costs that are directly associated with an RWIS. The capital costs for the Abilene bridge ice detection system were acquired directly from the vendor's proposal. These costs are for one RPU equipped with a modem, two pavement sensors, one subsurface temperature probe, a suite of atmospheric sensors, one CPU equipped with RWIS software, and turnkey installation of the system. The capital costs are detailed in Table 6.1.

Table 6.1 Capital costs for Abilene installation

Description	**No.**	**Item Cost**	**Expanded Cost**
RPU w/ enclosure	1	$6,446.00	$6,446.00
14.4K-baud modem	1	$124.00	$124.00
Roadway Base Tower Section	1	$885	$885
Roadway Middle Tower Section	1	$868	$868
FP2000 Surface Sensor (w/cable)	2	$4046	$8092
Subsurface Temperature Probe	1	$1088	$1088
Splice Kit	3	$35	$105
Relative Humidity/Air Temp. Sensor	1	$1856	$1856
Optical Infrared Precipitation Sensor	1	$2474	$2474
Wind Speed/Direction Sensor	1	$672	$672
SCAN for Windows Server (CPU)	1	$4,000	$4,000
SCAN for Windows User Interface	7	$200	$1,400
Turnkey System Installation	1	$14,000	$14,000
Total Capital Cost			**$42,010**

For a 50-year project life cycle, these capital costs will need to be reinvested every 25 years, since the RWIS life cycle is only 25 years. Therefore, there will be a $42,010 investment in year 1997 and the year 2022. Also, since the RPUs and the CPU will need to be upgraded every 5 years in order to keep up with new technology, there will be a $10,446 upgrade cost every fifth year starting in the year 2002 and ending in the year 2042.

Annual costs will include operations and maintenance costs, as well as the costs for meteorological services. The SCAN*CAST meteorological services will cost $350 per month. Thus, for a six-month winter season the annual costs for meteorological services will be $2,100. This is calculated in the equation below.

Annual Costs for Meteorological Services = ($350/month * 6 months/year) = $2100

O&M costs include maintenance costs for one-site and long-distance phone charges for communication between the RPU and CPU. As mentioned in section 4.2.1.1, the annual operations and maintenance costs can be estimated by multiplying $3000 by the number of sites and adding the cost for long-distance phone calls. Phone charges will be approximately $30 per month for hourly calls from the CPU to the RPU. The annual operations and maintenance costs are calculated below.

Annual O&M Costs = [$3000/site*(1 site)] + ($30/month*12 months/year) = $3360

6.3.2 *Indirect Cost Savings for RWIS*

The main areas of indirect RWIS savings will be through reduced patrolling and through more efficient winter maintenance operations. Since the TxDOT maintenance office in Abilene will be provided with real-time information and a 24-hour forecast of the pavement conditions on Interstate 20, it will be better able to manage winter maintenance operations and will need less time to patrol the area under RWIS influence. This time spent patrolling the interstate for road conditions is referred to as *spotting time.* As mentioned in section 6.2, the TxDOT maintenance office in Abilene spends about 16 hours — or two shifts — per storm patrolling the 80.47-km (50-mile) section of Interstate 20. It is estimated that RWIS implementation will cut spotting time on Interstate 20 in half, or by one shift [Garduno 1997]. Therefore, patrol savings can be quantified as follows using Equations 4.1 and 4.20 and the unit costs from Table 4.2:

Cost/patrol shift = 8hrs * [(2 * $25.50/hr) + $24/hr (truck cost)] = $600

Annual Patrol Savings = (1 patrol shift/storm)*(5 storms/year)* ($600/shift) = $3,000

Next, RWIS implementation should result in more efficient winter maintenance operations, which will result in an estimated 15 percent reduction in expenditures for labor, equipment, and materials (as discussed in section 4.2.1.2). Using Equations 4.3, 4.4, and 4.5 and the unit costs from Table 4.2, labor savings, equipment savings, and material savings can be estimated as follows:

Annual Labor Savings = .15 * [(192 man-hr/storm) * ($25.50/hr) * (5 storms/year)] = $3,672

Annual Equipment Savings = .15 * [(96 truck-hr/storm) * ($24/hr) *(5 storms/year)] = $1,728

Annual Materials Savings = .15 * [(160 yd^3 sand/storm * $8/$yd^3$) + (16 tons salt/storm * $60/ton) + (8 tons MgCl/storm * $400/ton)] * (5 storms/year) = $4,080

The total winter maintenance savings resulting from RWIS implementation will be the sum of the four types of savings mentioned above.

S_m = (patrol savings) + (labor savings) + (equipment savings) + (materials savings)
= $3,000 + $3,672 + $1,728 + $4,320 = $12,720 per year

6.3.3 *Social Cost Savings for RWIS*

The primary manner in which the Abilene RWIS will result in social cost savings is by reducing the number of automobile accidents that occur on Interstate 20 during icy or snowy conditions. The social cost savings resulting from the RWIS implementation can be estimated by taking the standard cost for each type of accident from Table 4.3 and multiplying that cost by the expected reduction of those types of accidents on Interstate 20. Using the methodology described in section 4.2.1.3, we were able to derive a simplified equation for the annual accident savings associated with RWIS implementation. This equation is expressed as follows:

$$S_A = .013\ (AADT * Freq * L) \qquad (4.19)$$

When we input the necessary data into Equation 4.19 for the RWIS on Interstate 20 near Abilene, we can compute annual accident savings as follows:

S_A = .013 (14,800 vehicles/day*5 storms/year*80.47 km [50 miles]) = $48,100

6.3.4 Net Present Worth of RWIS

The capital costs and annual costs associated with implementing a bridge ice detection system on Interstate 20 were calculated in section 6.3.1. The annual winter maintenance cost savings and accident cost savings associated with the LWCMS were calculated in sections 6.3.2 and 6.3.3, respectively. These costs and savings are summarized in Table 6.2. The cash flow diagram illustrated in Figure 6.1 shows how these costs and savings are incurred over time.

Table 6.2 Summary of costs and savings for Abilene RWIS

Cost Category	Amount
Capital Costs (total system)	$42,010 (every 25 years)
Capital Costs (RPU & CPU upgrades)	$10,446 (every 5 years)
O&M Costs	$3360 per year
Costs of Meteorological Services	$2100 per year
Winter Maintenance Savings	$12,720 per year
Accident Savings	$48,100 per year

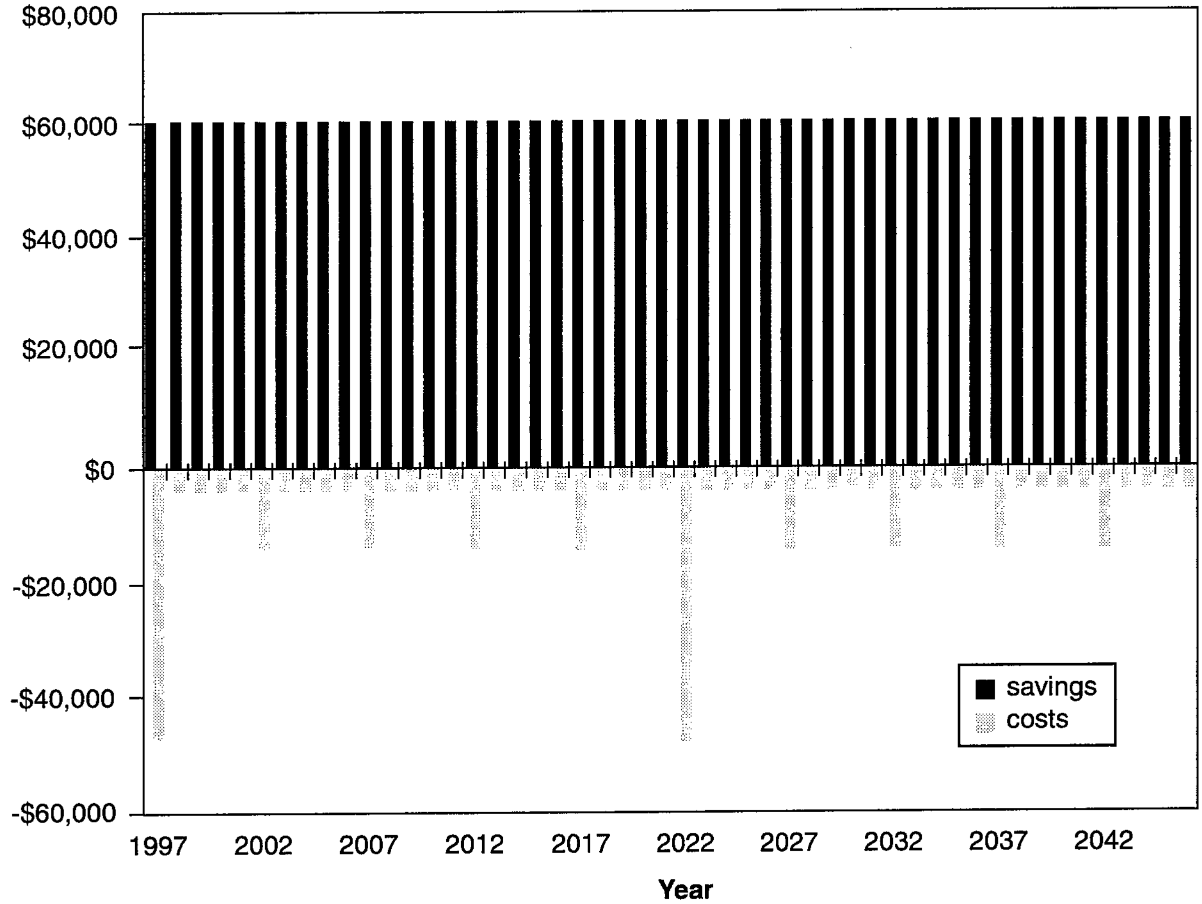

Figure 6.1 Cash flow diagram for Abilene RWIS

As mentioned in section 4.3, the mathematical expression for the net present worth is written as follows:

$$NPW = -\text{(One Time Costs)} + [\text{(Annual Savings)} - \text{(Annual Costs)}] * (P/A, i, n)$$

$$NPW = -CC + [(S_M + S_A) - (O\&M + MS)] * (P/A, i, n)$$

where

NP = Net Present Worth of alternative,

CC = Capital Costs,

S_M = Savings in winter/storm maintenance,

S_A = Savings from reduced accidents,

O&M = Operating and Maintenance costs,

MS = Costs of Meteorological Services,

(P/A, i, n) = Present value of aggregate series discount factor,

I = discount rate = 5%, and

$$N = \text{Number of years being aggregated} = 50.$$

When we substitute the values associated with our Abilene RWIS we get the following result:

$$NPW = -(\$42{,}010) + [(\$12{,}720 + \$48{,}100) - (\$3360 + \$2100)] * (P/A, 5\%, 50)$$
$$NPW = -(\$42{,}010) + (\$55{,}360) * (P/A, 5\%, 50)$$

The formula for calculating the present worth of aggregate series discount factor for an interest rate of 5 percent and a life cycle of 50 years is written as:

$$(P/A, 5\%, 50) = [(1 + .05)^{50} - 1] / [.05 (1 + .05)^{50}] = 18.26$$

When calculating the net present worth of the Abilene RWIS, we must also remember to factor in the reinvestment cost of $42,010 after 25 years and the RPU and CPU upgrade costs of $10,446 every 5 years. These costs will need to be discounted using the following discount factor for present worth of a future payment:

$$(P/F, 5\%, 50) = 1 / (1 + .05)^{n}$$

where ***n*** = number of years until future payment.

These discounted costs are then subtracted from the previous ***NPW*** formula. Thus, the incremental net present worth of implementing a bridge ice detection system on Interstate 20 near Abilene is calculated as follows (rounding the result to the nearest thousand dollars):

$$NPW = -(\$42{,}010) + (\$55{,}360 * 18.26) - (\$42{,}010 * .295) - (\$10{,}446 * .784) - (\$10{,}446 * .614) - (\$10{,}446 * .481) - (\$10{,}446 * .377) - (\$10{,}446 * .295) - (\$10{,}446 * .231) - (\$10{,}446 * .181) - (\$10{,}446 * .142) - (\$10{,}446 * .111) = \$923{,}000$$

6.4 ANALYSIS OF ABILENE CASE STUDY

This section analyzes the Abilene case study results. The first part of the analysis compares the net present worth of the LWCMS to the net present worth of other alternatives, including the "do nothing" alternative. Next, the analysis presents other benefits of the Abilene RWIS that were not accounted for in the model.

6.4.1 Comparison of Alternatives

The RWIS Decision Support Tool was applied to the Abilene TxDOT maintenance section to evaluate bridge ice detection alternatives. The site chosen for installation was on Interstate 20 at milepost 260. This site was selected because it is representative of weather conditions in the Abilene area and because of the high traffic volumes on Interstate 20. After quantifying the costs and benefits associated with the system, the Decision Tool estimated the net present value of an RWIS installed on Interstate 20 near Abilene to be $923,000 over a 50-year life cycle.

The incremental net present worth of implementing the RWIS can now be compared against the "do nothing" alternative. In this case, the incremental net present worth of doing nothing is set equal to zero. Thus, since the net present worth of implementing the RWIS is greater than zero, this would indicate that implementing an RWIS on Interstate 20 near Abilene is a cost-effective alternative to doing nothing.

The incremental net present worth of implementing an RWIS on Interstate 20 can also be compared against the net present worth of other alternatives, such as installing more than one bridge ice detection system. In this case, the costs and benefits associated with implementing more than one system on Interstate 20 need to be quantified and the net present worth needs to be calculated in the same manner as was the original system. If the net present worth of implementing more than one system on Interstate 20 is greater than $923,000, then the decision should be made to implement more than one RWIS if there is sufficient funding in the RWIS budget. The next section will discuss some other benefits of implementing an RWIS in the Abilene area that were not accounted for in the model.

6.4.2 Other Benefits of Abilene Bridge Ice Detection System

Other benefits of having an RWIS implemented on Interstate 20 near Abilene include reduced risk of liability, improved planning of construction projects, and reduced travel time and pollution costs. This system will help reduce the likelihood of a lawsuit because it will reduce the public's exposure to hazardous conditions. Also, by keeping historical records of the chemical content of the ice on Interstate 20, TxDOT can prove whether or not the road was adequately treated with de-icing chemicals during a storm. Such documentation could be useful in a liability suit brought against the state.

The RWIS will also aid the planning of construction projects by providing the TxDOT maintenance office with accurate forecasts of the weather and pavement conditions for that day. This will allow the agency to better schedule its year-round maintenance activities, such as repaving or restriping roads. The RWIS forecasts can also be used as a tool for construction contract time negotiations.

Finally, the RWIS will help improve traffic flow during inclement weather and reduce the amount of de-icing chemicals used per snowstorm. Such benefits will result in travel-time savings for motorists and less damage to the environment.

CHAPTER 7. CONCLUSIONS AND RECOMMENDATIONS

The major objectives of this research were (1) to develop a systematic methodology to evaluate the costs and benefits associated with RWIS implementation, and (2) to apply this methodology to actual case studies. These objectives were achieved through the development of an RWIS Decision Support Tool. This analysis tool provides a methodology by which different RWIS implementation alternatives can be evaluated and prioritized from economic, qualitative, and environmental perspectives.

From the results of the Kerrville and Abilene case studies, it is clear that an RWIS can provide TxDOT with a cost-effective solution to the problems of snow/ice removal and flooding of low water crossings. Of course, not every situation will warrant the implementation of an RWIS or LWCMS. This report described in detail many factors that are involved in the RWIS implementation decision-making process. When a highway agency such as TxDOT is considering implementation of an RWIS, a full cost-benefit analysis should be performed to justify the decision. In some cases, alternatives other than implementing an RWIS or LWCMS may be justified. For example, when traffic volumes and storm frequencies are sufficiently high, it may make more sense to replace a low water crossing with a permanent structure rather than implement a LWCMS, which only provides a temporary solution.

The rest of this chapter presents an RWIS implementation plan for TxDOT and provides recommendations for future research involving road weather information systems.

7.1 RWIS IMPLEMENTATION PLAN FOR TEXAS

As a result of this research, the following plan is recommended for the implementation of RWISs in Texas. RWISs should not be implemented on a statewide level in Texas. The decision whether or not to implement an RWIS should be left up to each district or county, and each decision needs to be justified through a full cost-benefit analysis. This cost-benefit analysis can be performed using the methodology of the RWIS Decision Support Tool presented in this report.

There appears to be a need for bridge ice detection systems where freezing and snowstorms are prevalent — mostly in north and northwest Texas. Also, there appears to be a need for low water crossing monitoring systems where flooding is prevalent, mostly in the hill country of Central Texas and in the Rio Grande valley. From the research, it is generally recommended that bridge ice detection systems be implemented at the district level and that LWCMSs be implemented at the county or area level. The are two reasons for this: (1) bridge ice detection systems are more expensive than LWCMSs and thus require district budgets, and (2) winter storms move over broad fronts, while flooding tends to be more localized.

7.2 RECOMMENDATIONS FOR FUTURE RESEARCH

The following are recommendations for future TxDOT research. First of all, efforts should be made to complete the low water crossing survey to ensure that responses have been received from all of the maintenance supervisors in Texas. This will provide TxDOT with a complete listing of all the low water crossings in Texas, including their need for low water crossing monitoring systems. The low water crossing database currently consists of responses from about 45 percent of the maintenance supervisors. Once the survey has been completed, its results can be used to calibrate the low water crossing regression model and to update the low water crossing accident rates.

Second, the cost-benefit model in the RWIS Decision Support Tool can be improved by incorporating other types of savings, such as averted litigation. If some correlation can be found between lawsuits and automobile accidents, and if an average cost per lawsuit can be established, then lawsuit savings can be incorporated into the model.

Also, it is important that some type of research be undertaken to determine the percentage of accidents occurring at flooded low water crossings where the motorist drives through a barricade or disregards a message sign. This is known in the RWIS Decision Support Tool as the *preventable factor*. If possible, further research should also determine the likelihood of a motorist heeding a flood warning or message sign when one is given. This was referred to in the model as the *obedience factor*. Accurate estimates for both of these factors would greatly improve the accuracy of the cost-benefit model for LWCMS.

The low water crossing regression model could be improved by looking at other factors that may influence the model, such as whether an alternate route exists, whether the site is on an emergency route, and the speed and duration of flooding at the site. If these factors are found to be statistically significant in predicting the value of an LWCMS, then they should be incorporated into the model.

Finally, a software version of the RWIS Decision Support Tool could be created to automate the RWIS decision-making process. The RWIS Decision Support Tool software would have to be flexible, user friendly, and menu-driven so that anybody could use it.

In conclusion, the RWIS Decision Support Tool provides a systematic methodology for evaluating the costs and benefits of various RWIS implementation alternatives from economic, qualitative, and environmental perspectives. The practicality of this methodology was demonstrated by using it to evaluate low water crossing monitoring systems in Kerrville and bridge ice detection systems in Abilene. Because of the simplicity and practicality of this methodology, it can be applied at either the project level (as in the case of the Abilene study) or at the network level (as in the case of the Kerrville study).

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