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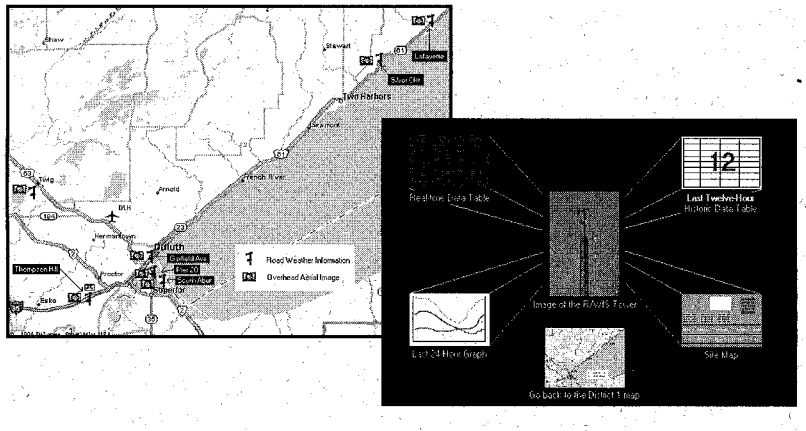

Next Generation R/WIS: Concept and Prototype Implementation

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16. Abstract (Limit: 200 words)

The Minnesota Department of Transportation (Mn/DOT) conducted a two-year study on developing a concept of the Next Generation Road/Weather Information System (NG-R/WIS). This report describes the concept and a prototype implementation of the NG-R/WIS in Minnesota District-1.

Traditional R/WISs offer limited scope of data types, limited communication methods, and proprietary incompatibility problems. The R/WIS in Minnesota District-1 experienced the typical problems of the traditional R/WIS. This project looked a solution to those problems—developing a new layered hierarchical architecture referred to as NG-R/WI.

Four layers--a sensor layer, a data integration, a database layer, and an application layer--form the basis of the NG-R/WIS form the basis of the NG/RWIS. This architecture allowed integration of heterogeneous systems through the data integration layer and provided structured data to applications through a standard relational database and computer networks.

This project developed three applications: web page service, automated voice service, and live stream-video service. The web pages and automated voice services provided solutions for unlimited access from anywhere, unified data format, ease of use, and no requirements of special terminals or software. The live video stream demonstrated integration capability of the system and provided a new class of information. The report concludes with the recommendations and future directions of the proposed NG-RWIS.

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Next Generation R/WIS: Concept and Prototype Implementation

Final Report

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EXECUTIVE SUMMARY

The present Road/Weather Information System (R/WIS) in the Minnesota Department of Transportation (Mn/DOT) District-1 consists of equipment from three different vendors: Surface Systems Incorporated (SSI), Vaisala LTD, and Climatronics. Each company provided hardware interfaces and data collection methods designed specifically for their own sensor packages and servers. Thus, the systems are incompatible and made it laborious to use and maintain them. For example: 1) the user must learn three different operating systems; 2) the user must understand three different data formats and presentation methods; 3) the user must remember three different user names, passwords, and access phone numbers; and 4) the system administrators must learn and maintain three different types of hardware interfaces and operating environments. As a result, the R/WIS data was difficult to access, understand, analyze, or utilize. In addition, the data dissemination methods were poorly designed. The users have been accessing the data through serial ports of the servers or modems attached to them. Since the servers cannot communicate with each other, three terminals must be connected or three modem connections must be made to each server in order to access all of the R/WIS data. Due to these limitations and the inconvenience of the systems, the maintenance engineers rarely used the data. Some useful features, such as graphics, were available but only to a few special terminals which were loaded with special software. This requirement further limited the availability of useful data to the maintenance engineers.

The goal of this project was to provide solutions to the above problems as well as to introduce new concepts and technologies to improve the quality of information and the methods of data warehousing and dissemination. The new system, referred to as the Next Generation R/WIS (NG-R/WIS), was designed based on a long term view of the overall system, technological and managerial growth, adaptation to different needs and environment, interaction with other information systems, and the flexibility to integrate new technologies or information. The resulting NG-R/WIS consisted of four interacting hierarchical layers: 1) Sensor Layer, 2) Data Integration Layer, 3) Database Layer, and 4) Application Layer. The two lower layers gather all

of the sensor data from the existing R/WIS systems and store them in the database layer, from which various applications are deployed. The key to this architecture is in the data integration and database layers where different data formats from heterogeneous systems are unified and the servers in the layers are networked together through the Mn/DOT Intranet to allow modern computer communication between the layers and users. As a result, users and applications can access the R/WIS data from anywhere within the Mn/DOT network. This integrated layered architecture solved the non-uniform data format and the limited access problem of the original system.

The user interface occurs in the application layer. Three applications were developed in this project: 1) web service, 2) automated voice-answering service, and 3) live video-stream service. The web service includes: 1) a realtime data table and a graphical display, both of which present information on what is occurring at the present time; 2) a 24-hour graph which gives information on the trend of the pavement, air, and dew point temperatures; and 3) a 12-hour table which includes the types of data that cannot be expressed in the 24-hour graph. These web pages are tightly integrated, easy to use, and can be simultaneously accessed from anywhere within the Mn/DOT network by many users. An automated voice-answering service was developed for users who do not have direct access to the Mn/DOT network. For this service, the users need only make a simple phone call to a preassigned phone number to get pavement and weather information. This service is particularly useful for the maintenance engineers who are working outside their Mn/DOT offices and also for travelers who do not have access to the Mn/DOT network. In addition, a live video-stream was broadcasted through the web pages to integrate visual information of road conditions to the traditional pavement and weather information. This visual information provides additional data that cannot be obtained from traditional R/WIS information, such as traffic conditions, and helps the assessment accuracy of road conditions. Since the video stream is broadcasted through the Mn/DOT Intranet, it can be also viewed from anywhere within the Mn/DOT network.

In conclusion, the goal of developing a next-generation R/WIS that can seemingly integrate

heterogeneous systems and can grow with new technologies while improving the old systems, was achieved through the introduction of a layered hierarchical architecture. The web integrated data dissemination methods, along with the automated voice answering service and live video streams, not only achieve the goal of designing an easy-to-use system, but also provide much higher quality information than the original system. However, there is still much work to be done to further improve the NG-R/WIS. Examples include integration of traffic information, snowplow information, pavement condition forecasts, new sensors such as slipperiness sensors, customized data delivery to specific groups or individuals, etc.

1 INTRODUCTION

1.1 Background

Road/Weather Information Systems (R/WIS) are specialized computer networks that collect, process, and disseminate information related to current and forecasted road/weather conditions to the end users. The R/WIS information is typically used by maintenance engineers and decision makers to help ensure that snow plowing and deicing operations are timely and effective. Other usages include decision support for transportation planning and travelers' information service.

In October 1992, the New Technology Research Committee (NTREC) of Minnesota Department of Transportation (Mn/DOT) established an R/WIS Task Force and charged it to study feasibility of implementing a statewide R/WIS in Minnesota. From this charge, the R/WIS Task Force performed a feasibility study and recommended a plan for implementing 276 sites statewide [1]. Since then Mn/DOT has committed to establish a statewide system and has been developing new R/WIS concepts and detailed implementation plans. In 1994, a mobile sensor vehicle was developed by Dr. Taek Mu Kwon at the University of Minnesota for thermal mapping purposes. Thermal mapping is a technique that has been used to find reasonably good locations of environmental sensor sites such that data interpolation between sites would be achievable [2]. In the following year, Mn/DOT conducted data collection from the state major highways for the purpose of thermal mapping using the developed vehicle. In 1996, Mn/DOT sponsored a workshop to promote implementation of a statewide R/WIS. In 1997, Dr. Taek Kwon proposed development of a next generation R/WIS (NG-R/WIS) as a demonstration project which includes development of a working prototype for the statewide model. The prototype introduces a new standardized open-architecture along with the new R/WIS concepts. These and many other efforts (not mentioned here) finally led to the development of a request for proposal (RFP) for 1998 R/WIS which calls for implementation of 75 new R/WIS sensor sites (hereafter it is called Remote Processing Units (RPUs)) and integration of the existing 17 RPUs.

1.2 Existing Problems

This section mainly focuses on identifying the problems related to the existing R/WIS servers and RPUs in District-1 (vicinity of Duluth, Minnesota). However, the similar problem statements would be applicable to the R/WIS presently installed in other parts of the Minnesota state.

Present R/WIS in District-1 consists of equipment from three different vendors, i.e., Surface Systems Incorporated (SSI), Vaisala LTD, and Climatronics. Each company provides hardware interface and data collection methods specific to their own sensor packages which can only work with their own systems. Therefore, the sensors and interfacing mechanisms are not compatible among different systems. In addition, three different proprietary servers from each manufacturer control their own RPUs in order to provide data storage and terminal connections for viewing the data. As a result, the terminal interface, data format, user interface, and the operating systems are all incompatible with each other. This incompatible and non-standard operating environment creates expensive inefficiencies in many areas of the system usage. For example, data collected from the seven RPUs must be viewed using three different computers and visual interfaces. These system differences make the data difficult to understand, share, compare, and analyze. The users and system administrators of the District-1 R/WIS must learn and maintain three different operating environments. Moreover, since the system components from the three companies are all incompatible, it requires a high maintenance cost. For example, if each vendor introduces a new version of server and terminal interface programs, three different copies must be purchased and installed. Also, the proprietary operating environment of these systems demands high development cost for new applications, thereby discouraging innovation by third party developers.

A second problem with the existing system is that the data accessibility is very limited. The basic method of data communication in all of the three systems is through serial ports of the server or modems attached to it. Since the servers cannot communicate each other, at a minimum

three phone lines and modems are required just to have one connection per server. Indeed, each server presently has only a single modem attached to it and has been used for both users and service access. With the present structure, if two operators want information on SSI sites simultaneously, only one of those operators will have access to the information even though three phone lines are available. Moreover, each user must obtain login names and passwords from each system. This means that the user must remember three phone numbers, login names, and passwords, along with three different command sets. It is truly too much to ask of maintenance engineers. Adding to these, the time it takes to make three seperate modem connections, typing in the user name and password, and getting the data from the server consume extraordinary work for such a limited amount of data. Due to these limitations and inconvenience, snowplow operators rarely use the system. The system should have been designed to be accessible from anywhere, simultaneously by hundreds of people with ease-of-use such that absolutely no learning is required. This project solves this problem by disseminating the information through World-Wide-Web (WWW) and by developing intuitive and easy-to-use web page designs.

A third problem with the present system is that even a small change requires modification of three systems. For example, when daylight-saving time starts and ends, it is not a matter of a Mn/DOT technician resetting the clocks. The proprietary nature requires that each company must be contacted so that a representative can dial-in to their servers and set the clock for Mn/DOT.

A forth problem is that there is no easy way of adding new sensors to the existing R/WIS. For example, the amount of sun radiation, visibility, and video data are extremely useful information for the District-1 R/WIS, and yet there is no easy way to add these into the existing system. It requires redesign of the RPUs and sever programs, which would be an enormous task. Even worse, no documentation is available for the design of internal interfacing mechanisms and the server programs. As of today, each manufacturer still does not follow any standards and builds proprietary closed systems which are incompatible with each other. This practice will continuously makes future expansion and innovation, such as integration of newly developed

sensors or improved technologies, extremely difficult.

A fifth problem is that developing a new application using the databases of the existing R/WIS is extremely difficult. First, there is no documentation available to users for accessing the database of each system, such that guess work and reverse engineering are required. Some systems do not even have any long-term databases. Second, the present system uses neither standard relational databases nor standard network communication protocols, such that the data cannot be accessed through the networked Mn/DOT computers. Third, the databases do not provide multiuser and multiprocessing capabilities, this makes it difficult to develop services which allow access from many users. Forth, databases are not compatible each other, thus it is difficult to develop an integrated application that works with all of the three existing systems. Consequently, a lack of standard database mechanisms makes future improvements of the system extremely difficult.

A sixth problem is that there is no easy way of verifying the accuracy of the data gathered by the RPU. A malfunction or miscalibration in a sensor continues to provide data (false data) instead of sending no data or an error message. There is a need for checking or validating the correctness of the data from the server side. Presently, no mechanism exists for such purposes.

Some useful graphics exist that are only available on the main computer at the DOT headquarters. These graphics can be useful for spotting and predicting potentially dangerous trends. For example, a graph can be used to compare air, freezing point, dew point, and pavement temperatures. If the graph shows that the air and dew point temperatures are approaching each other, then precipitation is likely to occur. If the air temperature is above the freezing point and the pavement temperature is below the freezing point, the pavement is likely to be covered with ice. Therefore, such information is very useful to the maintenance engineers and public, but it can be viewed only at the designated terminal in the DOT headquarters. The Next-Generation R/WIS provides the same information through a web page to everybody as long as they are connected to the Internet and have a common web browser.

1.3 Solutions and Project Goals

The goal of this project is to provide solutions to those problems described in Section 1.2 as well as introducing new applications and infrastructure. The new system should be designed such that it would integrate the pre-existing software and hardware with newly introduced technologies. It should not only improve the present information infrastructure, but also provide higher quality of information while solving the present problems. It should allow easy integration of new technologies and applications as well as easy modification of the existing technologies. The system should include standard relational databases and WWW technologies as its infrastructure. To distinguish this new system from the existing one, the new system will be referred to as the Next Generation R/WIS (NG-R/WIS). This system is proposed to have the following characteristics:

1. *Employment of a centralized data center which houses standard relational databases.* This centralized database concept will promote data collected or presented in different formats to be stored or retrieved in a uniform format. It provides standard open methods for database-access and can be evolved along with new data warehousing technologies. It provides a well developed set of standard management tools for the data.
2. *Employment of one uniform user interface.* The users are only responsible for learning one system as opposed to many different systems in the original system. Moreover, the system should be designed to be easy enough that users do not require any training.
3. *Dissemination of information through Internet.* Choosing this presentation method solves the limited access problem of the original system. In the new system, the only requirement for a user access is a web browser and an Internet connection. With this approach, many users (hundreds) can simultaneously access the information from anywhere in the world at anytime.
4. *Integration of video stream.* Video cameras can be installed at each site to provide

remote verification of sensor data. Also, visual information provides assessment of road conditions that was not possible with the traditional weather related data (see Section 5.2 for details). Video feeds should be accessible through the same web browser used to view the data.

5. *Easy to use graphical user interface.* Data itself may have very little value if it is not transformed into information that is useful and easy to understand. One of the primary goals of the new system is providing an intuitive graphical user interface that is simple and easy to understand. With a proper design, no learning should be required to use the system.

6. *Automated voice service through phone line.* This service is provided for the circumstance where the user does have direct access to the Mn/DOT Intranet or Internet. In such a case, the user can still call the automated phone service to get the R/WIS information. This approach provides a greater accessibility to the user by complementing the web service.

2 NEXT-GENERATION R/WIS: CONCEPT

2.1 System Design Goal

The Next-Generation R/WIS (NG-R/WIS) should be established on the basis of a long term view of the overall system, technological and managerial growth, adaptation to different needs and environments, interaction with other information systems, and flexibility to integrate new technology or information. The information gathered by the R/WIS should be standardized and widely accessible through Local Area Networks (LANs), Wide Area Networks (WANs) and Internet. The system should store data in standard relational database servers to allow efficient access to or from other systems or applications. The type of data collected should not be limited to only road/ weather related information. The system should be open to adopt any type of data as long as it helps the Mn/DOT needs and goals. The system should be designed as an open architecture; its architecture should be disclosed to the public for free competition of applications and system developments.

2.2 Architecture

The architecture chosen for the NG-R/WIS is a layered hierarchical system. The system consists of four hierarchical layers as shown in Figure 1: 1) Sensor Layer, 2) Data Integration Layer, 3) Database Layer, and 4) Application Layer. Each layer should be independent enough that technological advances in one layer should not lead to modification in the other layers. Each layer only represents a logical division but not the physical division, such that the architecture does not prevent a system from implementing more than one layer in one physical device. Each layer may have sublayers, but the architecture does not define the detailed division of sublayers. It is left to each individual implementation. Each layer is further described below.

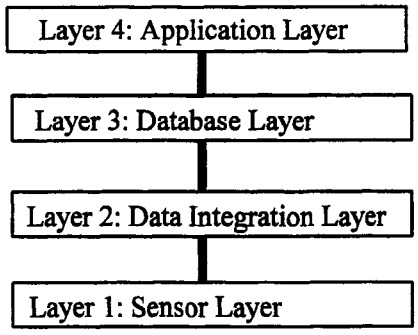


Figure 1: Layered Architecture

2.2.1 Layer 1: Sensor Layer

The sensor layer represents a collection of various devices that detect physical and logical occurrences of events. For quantization or representation of sensor values, Mn/DOT recommends the sensor data to conform the standard specified by the National Transportation Communications for ITS Protocol (NTCIP) [3]. The NG-R/WIS also conforms to the NTCIP standard. However, it should be noted that the NTCIP standard only specifies well defined environment sensor values, and some of newly developed sensor information is not defined yet. For example, the density and height of blowing snow is very critical information for road maintenance and travel, but is not specified in NTCIP. Therefore, NG-R/WIS simply recommends that any sensor that could help Mn/DOT goals can be added in addition to those defined in the NTCIP. This category includes new sensors in research and development stages. We identify the following components as the important devices and parameters for the sensor layer.

- **Atmospheric Sensors**. This includes sensors that measure *air temperature, humidity, dew point, precipitation type, precipitation rate, wind speed, wind direction and pressure*. All of these are commonly available from RPUs and specified in the NTCIP.
- **Pavement sensors.** The information measured by pavement sensors includes surface/subsurface temperatures, chemical factors, pavement freezing point and water/snow/frost/ice detection. Representations and quantization of all of these parameters are specified in the NTCIP and should be conformed.
- **Visibility**. It is defined as the greatest distance at which an object of specified characteristics can be seen and detected with the naked eye [4]. Reduced visibility is directly related to atmospheric conditions such as fog, smog, rain, snow, etc. Therefore, it is also desirable to combine the cause of reduced visibility along with the metric of visibility value. Since visibility is a critical information for drivers, it is recommended for inclusion in the sensor layer. The data format of visibility is specified in the NTCIP.
- **Snow depth.** This represents current depth of packed or unpacked snow on the road surface or adjacent area. The data format is specified in the NTCIP.
- **Slipperiness.** This value indicates measured coefficient of friction. Since friction of the road surface directly influences the braking distances of a vehicle, it is a critical piece of information for drivers. Maintenance engineers can utilize this parameter to maintain the road-surface friction to an appropriate level.
- **Blowing snow**. Blowing snow (includes drifting snow) can cause reduced visibility and slipperiness. This parameter may be expressed using a combination of several parameters: frequency, width, height, speed of movement, density and visibility.
- **Video stream.** Live video stream can be used to verify the parameters provided by the other sensors in a certain degree without sending a maintenance person to the site. Viewing the live video also greatly helps maintenance workers to assess the actual work conditions before going out to the site and allows them to be

mentally prepared. Moreover, it provides general visual information of the road such as shape, color and traffic. Also, reduced visibility, fire, or other severe problems can be easily observed through the live video stream. Therefore, video cameras are recommended for inclusion in the sensor layer.

- **Traffic sensor.** The parameters in this category includes average traffic speed, occupancy and vehicle counts. These values can be utilized in transportation planning and maintenance operations. The correlation between weather and traffic patterns could provide data for advance traffic management.
- **Solar radiation**. The amount of sunshine exposed to pavement is the most dominant factor that influences the temperature variation on the road surface. Therefore, it is an essential parameter for forecasting the road surface conditions and temperature. It is expressed in Jules per square meter and specified in the NTCIP. This sensor value is recommended for inclusion.

Some of the sensors listed above may not be available at the present time, but recommended for future inclusion in the sensor layer as they are available. The above listing does not include the status of road treatment such as when the road was plowed and salted, but such information can be also included as it is available in the future. The basic concept of the NG-R/WIS supports inclusion and integration rather than rigid definition and exclusion. Therefore, the above list only serves as an example of the present needs which may change over time.

2.2.2 Layer 2: Data Integration Layer

The data integration layer takes the role of a mediation layer between the sensor layer and the database layer. Its role is to collect data from the sensor layer, transform them into a uniform format acceptable to the database and transfer them to the database layer. In general, this layer will consist of two types of subsystems: Remote Processing Units (RPUs) and RPU Integration Servers (RISs). RPUs are the first data collection point in a remote site where several sensors are

installed and serve as a remote data unit. It should include the readings of all sensors in the site as well as the operating status of the sensors. Since RPUs also provide the first integration point of the sensor data, they should be designed to be expandable to add new sensors. RISs are typically located in the regional Mn/DOT headquarters and poll RPUs to receive the latest sensor data. RISs process data to a format appropriate to the central database, make connections to the central database servers and store the formatted data into an appropriate table. It should be noted that the final unification of the data format is done at the database layer. Therefore, if different data formats exist in the RPUs due to heterogeneous equipment from multiple vendors, RIS will be responsible for transforming them to a uniform format that is acceptable to the central database. For the communication between the database layer and the data integration layer, the standard TCP/IP protocol is recommended, since it provides the most widely accepted communication means to intranet and Internet infrastructure.

2.2.3 Layer 3: Database Layer

This layer combines all heterogeneous information collected from the data integration layer to a single unified resource through database tables. In order to maintain a strong standard conformation, the NG-R/WIS recommends the Structured Query Language (SQL) based databases in this layer. The databases in this category are also called a relational database. The most recent standard of SQL is specified in ANSI SQL-92. The databases used in this layer must conform to this standard. Open Database Connectivity (ODBC) is a standard application program interface (API) for database access that is supported by nearly all database vendors and independent software developers. All database servers used in this layer should conform to the most recent ODBC. Presently, ODBC is an ANSI and International Standard Organization (ISO) standard.

In the actual implementation, the database layer should consist of multiple database servers that are connected through a computer network. In order to avoid loss of a large data table by a server failure, it is recommended that the database size of each server be limited to a certain size. A

single large table usually requires longer search and query time and is prone to a single point failure. On the other hand, creating many small tables can increase the complexity of query and maintenance. Therefore, the size of the tables in the database should be determined to reflect the optimal performance in both search time and maintenance.

2.3.4 Layer 4: Application Layer

This layer includes various applications that utilize the data available from the database layer. In general, the application layer does not impose any restrictions on its data format or in the presentation methods. Applications should have full freedom in their presentation methods. However, their access frequency and methods to the databases must be efficient, such that they do not waste the database server time.

It is possible that some applications may directly obtain data from the data integration layer, but its status should be still tied to the database layer. For example, suppose that we want to create an application that sends live video-streams of RPU sites to the users through web pages. Since video streams consist of enormous amounts of data, it is clearly not suitable to store them into a database table. In this case, the database should only store the status and statistic information about the video streams such as where the camera is located, what is the resolution, how many users are allowed and what is the IP address. The video stream is then directly transmitted through web pages.

Several applications are identified in the NG-R/WIS project and listed below. As new technologies are available in the future, some of the listed applications could be obsolete and replaced with new applications.

Data dissemination methods

- World Wide Web
- File Transfer Protocol (FTP)

- ❑ Automated or on-demand email warning system
- ❑ Automated or on-demand FAX delivery
- ❑ AM and FM radio broadcasting system
- ❑ Automated pager system
- ❑ Automated voice answering system
- ❑ Wireless cell phone delivery system

Forecasts

- ❑ Pavement temperature
- ❑ Pavement condition
- ❑ Blowing or drift snow
- ❑ Amount of snowfall
- ❑ Traffic

Service

- ❑ Travel advising system
- ❑ Crew scheduling for maintenance
- ❑ Incident detection and monitoring system
- ❑ Decision support system
- ❑ Traffic control support system
- ❑ Snowplow information network
- ❑ Route optimization system for snowplow trucks
- ❑ Input to variable message signs

3 EXISTING R/WIS AT MN/DOT DISTRICT-1

Presently, Mn/DOT District-1 has three R/WIS units made by three different companies. These systems include three RPUs and one server from Vaisala, three RPUs and one server from SSI, and one RPU and one server from Climatronics. For the NG-R/WIS project, only two systems, one from Vaisala and one from SSI, were considered. The system from Climatronics was not included in the project due to its extremely slow communication speed (300 baud rate) and lack of technical supports. This section briefly describes the existing system along with the available environmental sensor information.

3.1 Vaisala System

The Vaisala system consists of three RPUs in the field which are linked by a Unix based server located at the District-1 Mn/DOT headquarters. The three RPUs are installed at the following locations:

- TH61 at mile point 30.49, Silver Cliff Tunnel, approximately 4 miles north of Two Harbors. This RPU is called Silver Cliff station.
- I-535 on the Blatnik Bridge over St. Louis Bay at Pier 20 on the Wisconsin side. This RPU is called Pier 20 station.
- I-535 at the south abutment on the Wisconsin side of the Blatnik Bridge over St. Louis Bay. This RPU is called South Abutment station.

The pictures of three sites are shown in Figures 2, 3, and 4. The communication method used to poll the Silver Cliff station is a microwave link. The Pier 20 and South Abutment stations are polled through a combination of UHF-radio and microwave links. The server at the District-1 headquarters polls these three field stations every 10 minutes and maintains a small database. The user interfaces are done through a special graphic terminal which is provided by the vendor. The useful information is provided by the two terminal screens as shown in Figures 5 and 6, which we later convert to a data entry form of the SQL database in NG-R/WIS.

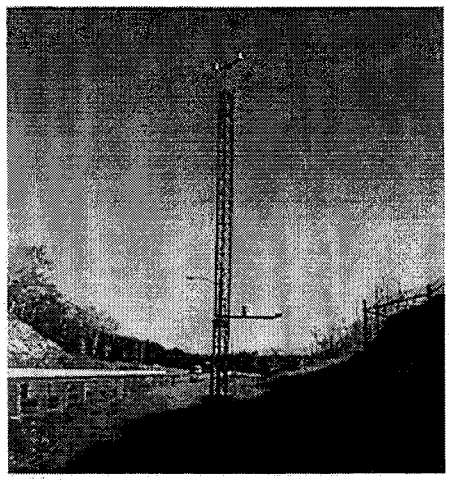


Figure 2: Picture of Silver Cliff RPU

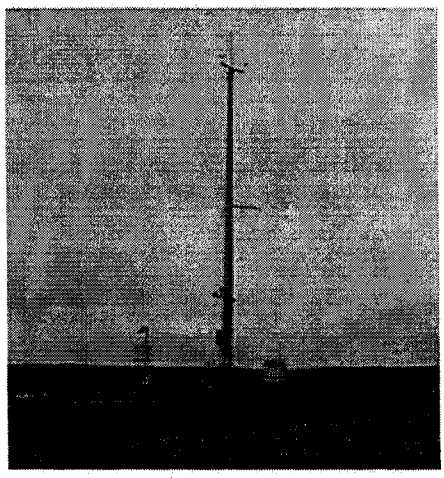


Figure 3: Picture of Pier 20 RPU

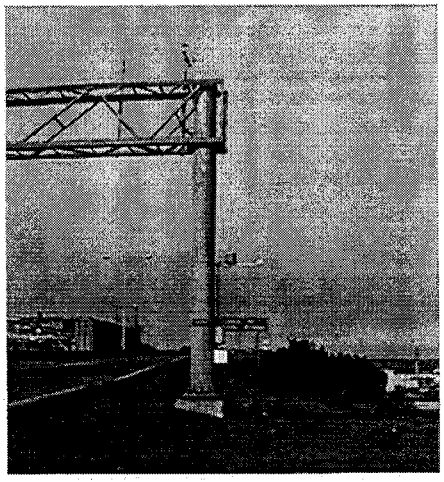


Figure 4: Picture of South Abutment RPU

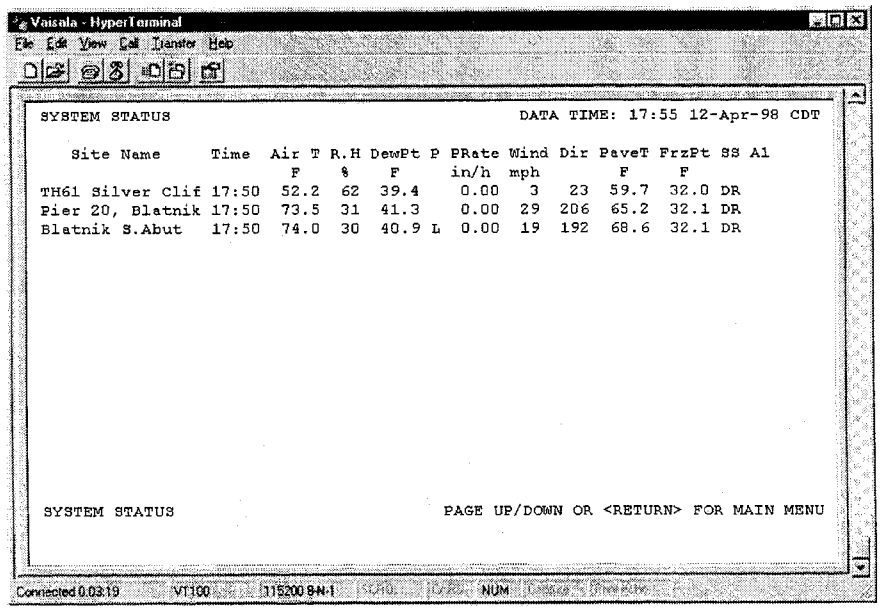


Figure 5 System status page for Vaisala sites

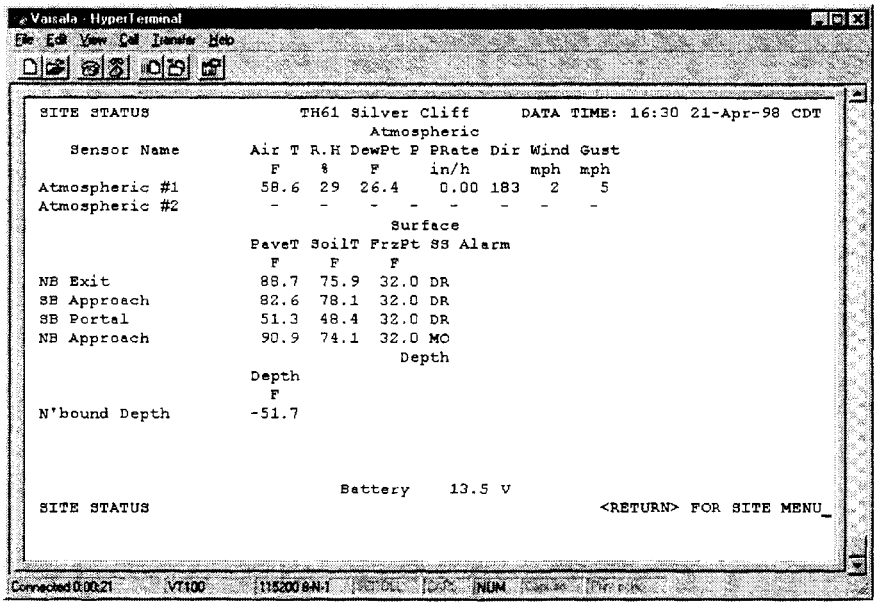


Figure 6: Terminal screen interface for Vaisala sites

Figure 5 is a system status screen which provides a summary of weather data at all sites. This screen is useful for a quick overview of the sites. Figure 6 is an example of a site data page in which all detailed information about the pavement sensors are provided. The sensor data at each site could be categorized into two types. The first type is the atmospheric information which consists of air temperature, relative humidity, dew point, precipitation, precipitation rate, average wind direction, average wind speed, and gust wind speed. The second type is the pavement information which includes pavement temperature, soil temperature, sub-probe (also called as a depth probe) temperature, freezing point, and pavement conditions. The complete list of sensor information is shown in Appendix-A. As mentioned earlier, due to the connection requirement of a special terminal through serial ports or modems, it is only available to a small number of people within the Mn/DOT. Also, the user has a burden of obtaining a proper terminal. Since the cost of maintaining analog phone lines is expensive, Mn/DOT District-1 presently has only one modem line allocated per server and they are used for both the system maintenance and the user interface. This means that only one user can access the Vaisala server at any given time

through a modem. Another critical limitation of this system comes from the proprietary nature of the sequential database used in the server. This database is primitive and cannot communicate with other databases. Presently no application is running using this database. Due to these limitations and the problems discussed in Section 1.2, the data collected using the Vaisala system has been underutilized.

3.2 SSI System

The SSI system consists of three RPUs located in the field and a server located in the District-1 headquarters. The server polls the three RPUs every five minutes. The three RPUs are located at the following sites:

- I-35 at mile point 255.91 located approximately 700 feet northeast of Garfield Avenue in downtown Duluth. This RPU is called Garfield Avenue station.
- TH 61 at Lafayette Tunnel approximately 8 miles north of Two Harbors. This RPU is called Lafayette station.
- I-35 at mile point 247.9 located between Thompson Hill and Nopeming just south of Duluth. This RPU is called Thompson Hill station.

The pictures of these sites are shown in Figures 7, 8, and 9. The communication means used in polling the Garfield Avenue and Thompson Hill stations are the plain analog voice-graded phone services. The Lafayette station is polled through a microwave link. The SSI server is also based on a Unix operating system and can be accessed through a terminal interface. A sample terminal screen is shown in Figure 10. The screen printing method in SSI is different from that of Vaisala. The SSI interface does not use any escape sequences of terminal characters while the Vaisala system does. This makes access easier to the SSI server than to the Vaisala server from the programmer's point of view.

Figure 7: Garfield Avenue RPU

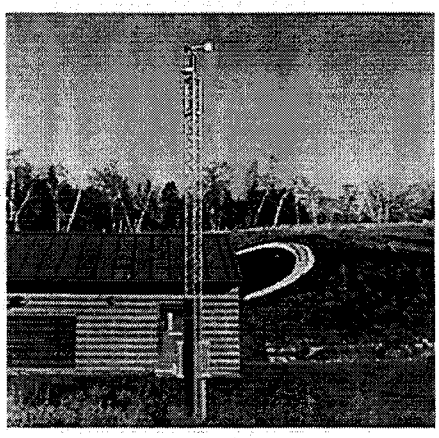


Figure 8: Lafayette RPU

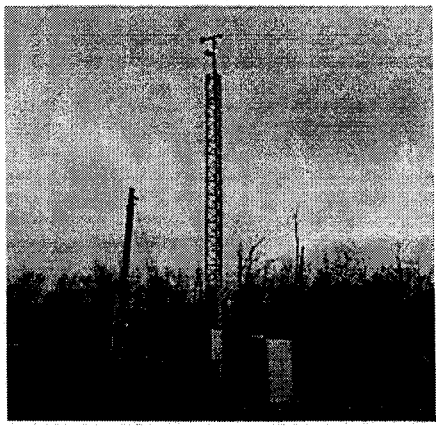


Figure 9: Thompson Hill RPU

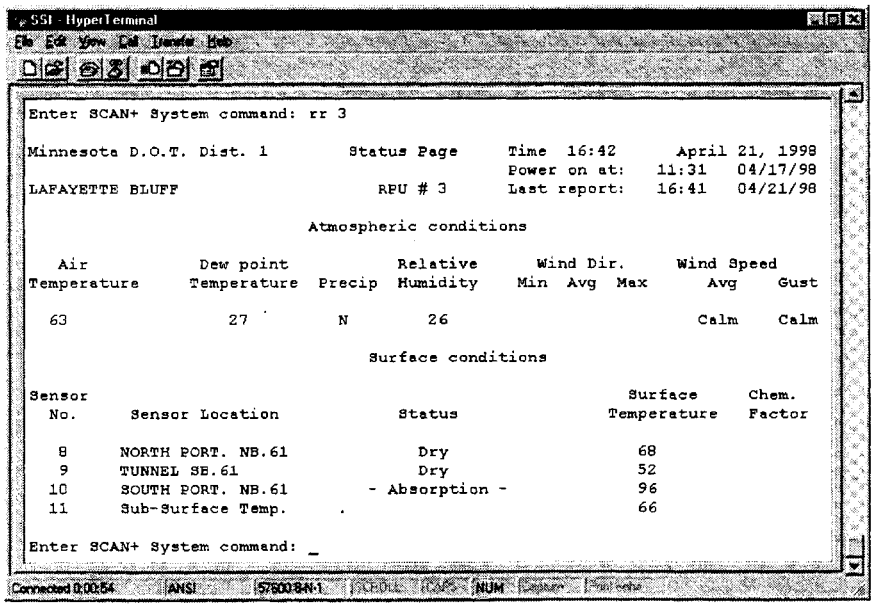


Figure 10: Terminal screen interface for SSI sites

Similar to the Vaisala system, the SSI system provides data from a set of atmospheric sensors and a set of pavement sensors. However, many differences exist in the types of the data and their expressions. A complete list of the SSI sensor information is shown in Appendix A. A few differences are described here. The SSI system does not provide any data on the precipitation rate although it is an important parameter, while the Vaisala system does. In the pavement sensor data, the SSI RPUs provide a measurement of chemical factors which indicate the percentage of chemical contents dissolved in the pavement precipitation. The Vaisala system does not provide this parameter. The SSI system lacks in providing the freezing point information while it is available from the Vaisala system. The expressions of pavement conditions are widely different in the two systems. For example, Vaisala uses "MO" to represent a moist condition on the pavement, while SSI uses the term "absorption" for the same condition. A complete list of conversions to a unified form are discussed in Section 4.2. The limitations of the SSI system are similar to those of the Vaisala system discussed in Section 3.1.

4 IMPLEMENTATION OF THE NEXT-GENERATION R/WIS AT MN/DOT DISTRICT-1

This chapter describes how the concept of the NG-R/WIS developed in Chapter 2 is actually implemented in the R/WIS of Mn/DOT District-1. Figure 11 shows a block diagram of the four-layer architecture which was actually implemented. The sensor layer which is shown at the bottom of the figure is composed of the existing atmospheric and pavement sensors of the Vaisala and SSI sites. The integration layer consists of three sub-layers, i.e., an RPU sub-layer, an RPU server sub-layer, and an integration server sub-layer. The RPU servers collect data from their RPUs, while the integration server collects data from the two RPU servers and then passes the data to the database layer through the Mn/DOT Intranet.

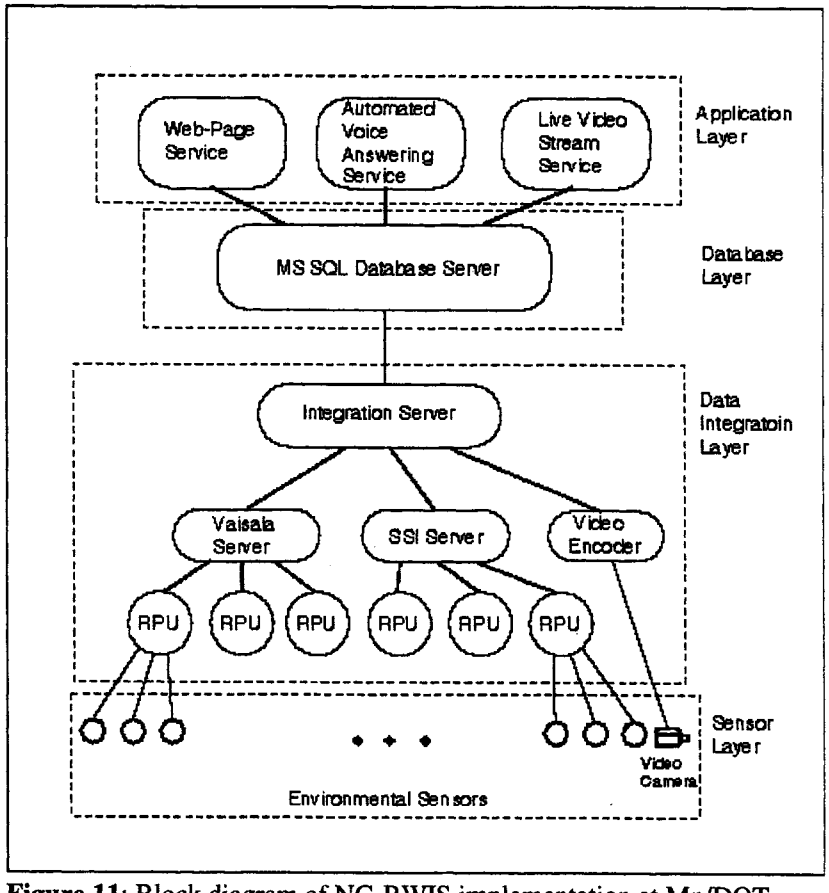


Figure 11: Block diagram of NG-RWIS implementation at Mn/DOT District-1.

A database server is located at the District-1 headquarters and connected to the Mn/DOT network, through which it provides data access to the application layer as long as the application is connected to the Mn/DOT network. In the application layer a web service is provided, from which access to the R/WIS information is available to anyone who has an Internet connection. If one does not have an Internet connection such as while on the road, she or he can call the automated voice answering service where the desired information can be obtained through touch-tone navigation. Each layer is further described in the following sections.

4.1 Sensor Layer

Since one of the characteristics of NG-R/WIS is the ability of integrating different types of sensors from heterogeneous vendors into a unified form of data, the system adopts all of the present environmental sensors from the District-1 Vaisala and SSI systems.

In addition to the SSI and Vaisala sensors, one sensor independent of the existing servers was added. The added sensor was a video camera for broadcasting a live video stream of the road conditions near the sites to the end users. With the advances in Internet technologies, sending video signals through the Internet is inexpensive and efficient. Moreover, video images have been proven to provide extremely important information in many transportation applications and have been widely used. For example, video images can be used to detect reduced visibility [4], blowing snow, traffic incidents, traffic flow, road maintenance, and other visible conditions. Another important use of video information is in verification of the collected data from the environmental sensors. With the present RPUs and server set up, there exists no easy way of verifying whether the sensor data coming from the field is true or not. In fact, the accuracy of the data is one of the biggest concerns that the maintenance engineers have been raising [5]. Video information can be used to confirm some of the R/WIS sensor data. For example, if the pavement sensor indicates detection of snow, the image seen from the video camera should show the road color as white. Therefore, the sensor layer was implemented using the existing sensors and a color video camera.

4.2 Data Integration Layer

The data integration layer consists of three levels of sub-layers as shown in Figure 11: an RPU sub-layer, an RPU server sub-layer, a data integration server sub-layer. The RPUs, located in the field and at the bottom of the data integration layer, collect data directly from the field sensors, pack the data to an efficient form for transmission and wait until it is polled. There are six RPUs installed in the field (see Chap 3 for more details), from which three of them are Vaisala units and the other three are SSI units. Each RPU server polls their three RPUs through a phone line or microwave links in a predetermined interval. The polled data are then stored in the local disk storage of the server. In this project, no additional work was done to improve the RPU or its server side codes. Both systems worked well in bringing the data to the central office, and there was no need for modifying the working system. However, the RPU servers were not connected to the Mn/DOT network, so there was no direct network path from the database server to the RPU servers.

Since the only way that another computer could access the data at the RPU servers was through a serial port with a modem, an intermediate unit that could communicate with the RPU servers and reroute the data to the database server through the Mn/DOT network was needed. This intermediate unit was referred to as an integration server. If the RPU servers were connected to the Mn/DOT network, the data could have been directly passed to the database layer. However, this approach had a problem, the research team was not allowed to modify the RPU server hardware and programs. Therefore, introduction of an integration server was imperative. The integration server was implemented as an NT standalone server (Version 4) with an Ethernet connection to the Mn/DOT network. The role of the integration server is truly integrating the data from different sources. It also serves as a video server from which video signals are rerouted from the live encoder to the end users. Since it also serves as a video server and possibly for other new sensor-data in the future, a large amount of memory was needed. For this reason, 128 Mega Bytes of random access memory (RAM) were installed in the integration server.

The integration server polls the RPU servers every three minutes through a dial-up phone line. The three minute interval was chosen in order to capture the five minute and ten minute data-refresh cycles of the SSI and Vaisala systems, respectively. Since the RPU servers only know terminal interfaces, a program residing in the integration server must remove all unnecessary control characters and extract the true information. This process is somewhat tedious and thus described in Appendix B. Once all data items are collected, the integration server connects itself to a database server through the Mn/DOT Intranet and sends an insert command to the database to store the R/WIS data.

Since the types of data collected from the RPU servers are not homogeneous, the integration server takes the role of unifying these data to a single form. Table 1 summarizes the unified specification of atmospheric and pavement data developed in this project along with each vendor's format. The basic philosophy used here was inclusion. This means, if the same type of sensor data is not available from one vendor but available from the other vendor, the data type was included in the unified form. For example, the parameter, freezing point, is only available from the Vaisala unit as shown in the Table 1. In this case, the unified form includes the freezing point.

Notice in Table 1 that the wind direction of the unified form is represented in a cardinal direction (due to the Mn/DOT's request), but it was actually stored in the database as degrees following the NTCIP recommendations. The conversion was done through mapping from (0°, 45°, 90°, 135°, 180°, 225°, 270°, 315°) to (N, NE, E, SE, S, SW, W, NW), approximating any value between them to the nearest. According to Mn/DOT users, a cardinal direction was much easier to understand than the unit of degrees. Moreover, they expressed that accurate degree of wind direction is not needed in their applications. Therefore, all of the user interfaces in the application layer for the wind directions were expressed using the cardinal direction.

The representations of pavement conditions in both systems were quite different. Therefore, a unified specification was also developed for the pavement conditions and summarized in Table 2.

This unified format of data is used in the web data dissemination and to store the data in the database (see the sample web page of the realtime data-table shown in Figure 16).

Table 1: Unified format of RPU data

Unified	**Vaisala**	**SSI**
SiteName	Name	Name
DateTime	Data Time	Time
AirTemp F	Air F	Air Temperature
R.H. %	R.H. %	Relative Humidity
DewPoint F	DewPt F	Dew Point Temperature
Precip [Y/N][Rate in/h]	Prate in/h	-
	P	Precip
Windspeed mph [Avg][Gust]	Wind mph	Wind Speed Avg
WindDir [Avg][Max][Min]	Dir	Wind Dir Min
	-	Wind Dir Avg
	-	Wind Dir Max
FreezP F	FrzPt	-
PaveTemp F	PaveT	Surface Temperature
PaveCond	SS	Status
SoilTemp F	SoilT	Sub-Surface Temp.
ChemFactor	-	Chem. Factor
Alarm	Alarm	-

Table 2: Unified format of pavement conditions

Unified	**Vaisala**	**SSI**
Dry	DR	DRY
Moist	MO	Absorption, Dew, or Absorption @Dewpt
Wet	WE	WET
Wet & Treated	WT	Chemical Alert
Frost	FR	FROST
Snow/Ice	SN or IC	Snow/Ice Alert
Treated	TC	-
Sensor Short	SH	-
Unknown	?	?

4.3 Database Layer

The database layer consists of one or more relational database servers and provides a structured query and maintenance of data to the application layer. We chose an NT server 4.0 with a Microsoft SQL (MS SQL) 6.5 for implementation of this layer. The NT operating system was chosen due to its low cost and wide spread use of operating systems within Mn/DOT. The MS SQL was chosen, since it conforms to the ANSI SQL standard and integrates very well with the NT operating system.

A relational database is constructed based on one or more tables which hold the data. It is based on a set rather than a list and provides efficient retrieval of data. It works with multi-users and multi-processing allowing simultaneous access from many users. Many databases can exist

within one database server, and retrieval of data can be accomplished in relation to other databases. Moreover, many database servers can coexist in a network and share or distribute the data. Often, mirroring of databases is implemented in two database servers to minimize the possibility of losing all data. Database servers can generate automated emails and web pages if a pre-specified condition occurs. Most database managerial functions are built in and can be executed without stopping the regular activities of the database. These include back-up, generation of a new database, mirroring, etc.

For implementation of the NG-R/WIS database layer, a database named "rwis" was created. In order to control the growth of the database search time, the maximum size of the database was set not to exceed 2 Gbytes. Since the NG-R/WIS project includes six sites, six table objects were created. These database objects are:

dbo.garfield
dbo.lafayette
dbo.pier_20
dbo.s_abut
dbo.silver_cliff
dbo.thompson

If many sites are implemented in one database, it is recommended that a separate table be created for maintaining site names, locations, maintenance information and other parameters that are not frequently changed. The SQL script information for creating the above tables is shown in Appendix C. For each table, a trigger was created to update the historic data-table in the web page whenever new data is inserted in the corresponding table.

Microsoft Visual Basic Enterprise Edition provides tools for easy access to the MS SQL 6.5. Therefore, all programs for adding new data to or retrieving data from the database were written in Microsoft Visual Basic.

There are several issues that are very important in creating and maintaining the database. These issues are briefly discussed here. The first issue is, how big the size of the database should be. In MS SQL and in most relational databases, the size of databases can be expanded as much as the hard disk space is allowed. However, it is important to plan ahead and decide how much you would want to allow the database to grow, i.e., determine the maximum allowable size ahead of time. It is very important to consider the reasons and factors for this decision, which are discussed below:

- As the size of database tables gets larger, the search, sort, insert and retrieval operations will take longer since the relational database is based on a set concept. For example, the insert command in SQL, which occurs frequently in the R/WIS database, checks all entries of the table before executing the insert operation in order to prevent any duplicated rows. Consequently, if the size of the table is very large, it will take a significant amount of time in checking the duplicated data before inserting the values. Similarly, such slow down could occur in query operations. Therefore, creating a single large data table is not desirable for the realtime requirement of R/WIS applications; the database designer should avoid storing every data in a single large table.
- Operating a single very-large database is prone to *a single-point failure*. For example, suppose that one of the database operators mistakenly dropped the table, then every data in the table will be lost unless it was backed up. Also, if the hard-disk of the server crashes, no data would be available until the server is restored. Therefore, smaller size databases distributed over multiple servers are preferred in the NG-R/WIS database layer in order to increase the reliability of the data warehousing operation. As another alternative to increase the reliability, database mirroring could be applied. However, mirroring of a large database is again less efficient than a smaller size.
- Small fragmented databases over many servers could drastically increase the burden of management and complicate the development of applications, although

it may drastically reduce the risk of losing all data. In general, simple well planned medium-sized databases are most likely desirable for the R/WIS databases.

- Database backup plans are very important to safeguard the database from server failures. Since database engines heavily use hard-disk access for its operations, the disk is almost always spinning during database operations. Therefore, it is safe to assume that the hard-disk will eventually fail in the future, thus the database should be backed up regularly. The question is how frequently should the database be backed up at what level. The required backups include master db, R/WIS db, and transaction logs. A proper plan should consider the size of the databases, transactions, and priorities. In fact, the backup plan should be laid out when the databases and tables are created.

In the District-1 NR-R/WIS design, since the complete implementation requires creation of tables for six sites, only one database server was used. The maximum size of the database that houses the six tables was limited to 2 G bytes by creating a separate partition for the R/WIS database device. This partition holds the master db and all site tables as well as the transaction logs. The next question is, how many rows should be allowed in each table. In one year, the maximum number of rows in a table would be (12*24*365)=105,120 rows, since the shortest data refresh interval is five minutes. The search time of this many entries took long enough to slow down the response time of the application layer. For example, the automated voice service which will be described in Chapter 5 queries the most recent data from the database whenever a call is received. With the table size of one year of data, the retrieval time was so slow that the user had to wait almost 30 seconds in the worst data traffic condition. One way of resolving this problem was creating two databases: one short-term database and one long-term database. The concept and operations of these databases are described in the following paragraphs.

(1) Short-term Realtime Database

This database holds data from 2 to 6 months old up to the present. At the end of every month data is moved to a long-term standby database. The role of this database is to

provide short term storage for the realtime data. It provides services to those applications that require frequent accesses of the most recent data. Example applications include the real-time web data table and the realtime data voice service. As the data gets older than a specified time span, it is moved to a long term standby database, from which long-term historical data services are provided. In this way, a long-term database will be available on line, while keeping the most frequently accessed database to a smaller efficient size.

(2) Long-term Standby Database

A long-term standby database is a database that is served for suppling data for applications which require a large chunk of data, but do not have to query the database in realtime. For example, monthly graphing is needed to be performed only once a month, and it would not make much difference even if the query takes one or two minutes. This database collects data from the realtime short-term database at the end of every month. This database will hold data up to maximum of two years. Every year, one year of the past data will be archived to a permanent storage using a permanent storage device like CD-Rs (write once CD ROMs).

(3) Permanent Retired Database

A permanent retired database is an off-line database which is stored in CD-Rs. It serves as an archive of R/WIS data history. Therefore, the data format should be universally accessible ASCII format with the meaning of the data supplied right in the same disk. Yearly data is saved from the long-term standby database.

By creating the three stages of databases as described above, one to two years of data could be available on line, while keeping the most frequently accessed database to a smaller size. An additional description on how to manage the database is described in Appendix D.

The NG-R/WIS implementation in District-1 includes a live video stream as a part of the system. The question is how do we want to integrate the video stream to the NG-R/WIS architecture.

Since the amount of data produced by a video digitizer is enormously large and does not require frequent retrieval, only the information about the video stream should be stored in the database. Such information may include the location of camera, connection type, data encoder characteristics, installation and maintenance data, etc. A similar approach could be made, if an application requires a large size of text. In this case, the database may store the location, name, size, last update time, etc. of the file.

4.4 Application Layer

For this NG-R/WIS project, three applications were developed and implemented. These are data dissemination through web pages, a live video stream delivery, and automated voice answering system. This section describes a brief summary of these applications. The details are described in Chapter 5.

One of the goals set out for this NG-R/WIS project was to allow the users to have access to all of the R/WIS data as easy as possible regardless of the incompatibility problems which may exist among sensors, RPUs, and RPU servers which are provided by different vendors. Users should not need any special tools or skills and should be able to access the data from any location. This goal was achieved through two means. The first means was presenting the data through Internet/Intranet web pages. Since almost all of the Mn/DOT computers are connected to Internet, anyone having a standard web browser is now able to access the data. The web pages were designed using hyper links of text and graphics, so it is extremely easy to navigate and get the desired information. The web pages presently provide various tables and graphical designs for user interfaces. The details of the main features are described in Chapter 5. It is expected that the presentation by web pages will be continuously improved in the future to provide even more intuitive and easy- to-use data presentations along with more content.

Sometimes, the users of the NG-R/WIS may not have an Internet connection. This happens,

when the maintenance engineers are working on outside the Mn/DOT headquarters for such as snow removal operations, where real-time information on the pavement conditions and the surface temperature is needed. In order to provide the R/WIS information where no Internet/Intranet connections are available, this project included development of an automated voice answering system. With this service, users can simply dial-in with a phone and can receive the R/WIS information through voice recordings by navigating through the menu using the touch-tone keys of the telephone set. The voice information is produced by a voice server which retrieves the most recent data from the main database and converts them into a voice file. Anybody who knows how to use a regular phone should be able to use this system. The details on the design aspects of the voice service are discussed in Section 5.3.

Integration of real-time video is another enhancement of the information provided by the NG-R/WIS, which is typically not available from the traditional R/WIS. It was found that visual information of the road scene significantly improves the accuracy of the road condition assessment when it is incorporated with the numerical and graphical R/WIS data. Moreover, live video information provided additional information that cannot be obtained from the traditional weather related sensor information such as floods, road damages, etc. Therefore, a live-video stream was integrated to the NG-R/WIS as part of the application layer. Further details on video implementation are discussed in Section 5.2.

5 APPLICATIONS DEVELOPED IN THE APPLICATION LAYER

5.1 Web Service

One of the system deficiencies of the existing District-1 R/WIS, as described in Section 1.2, was the inability of data delivery to many users with a uniform easy-to-use data presentation. This deficiency was solved by disseminating information through web pages. The web service delivers almost unlimited connections to the users from anywhere in the world as long as an Internet connection exists. One of the big advantages of this method of data dissemination is that neither learning of the system commands nor passwords are required, since a standard web browser is the only software needed to access the R/WIS information. A proper design of web pages could also present the R/WIS information to the users as easy as possible.

To implement the web service, a web server running Windows NT 4.0 was implemented initially as a Mn/DOT Intranet service. The Internet service was implemented using the Microsoft Internet Information Server. Later, Wisconsin DOT and others requested access to the Mn/DOT R/WIS web pages. Therefore, a cache server was specially created to provide the web service outside the Mn/DOT network . Creation of a cache server was necessary due to the fire-wall protection of the Mn/DOT network.

Since our goal was providing information to users as easily as possible, the design of the web pages was based on intuitive graphical user interfaces. Envisioning a state-wide R/WIS system, the web page starts from a state map as shown in Figure 12. The state-map then leads the user to a District-1 RPU map as shown in Figure 13. The RPU sites are hyper-linked to red circles, and the sites' aerial photographs are linked to the blue squares. One of the areal photographs is shown in Figure 14 which provides scenery of the area. The red circles lead to the corresponding site menu which provides various sensor information as shown in Figure 15.

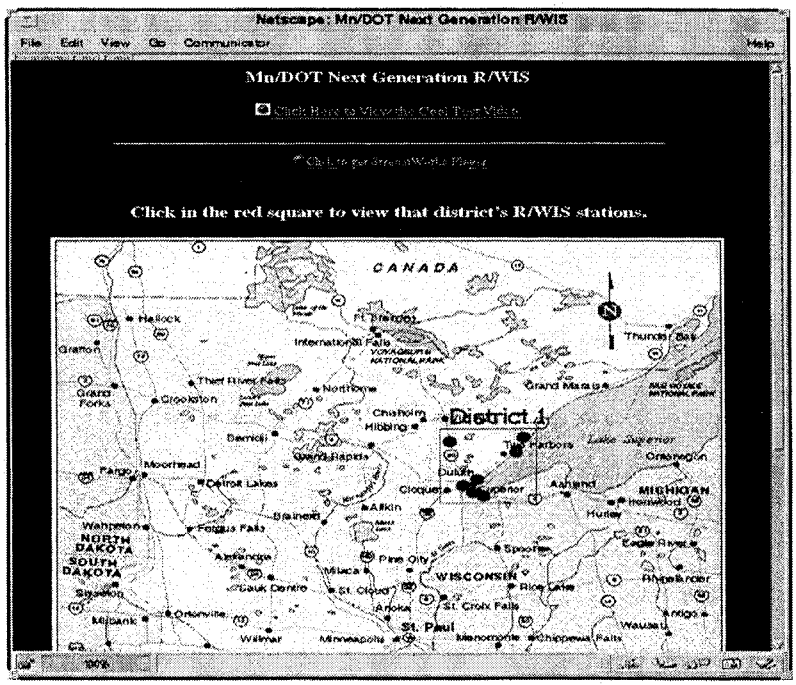


Figure 12: Front page of the NG-R/WIS web site

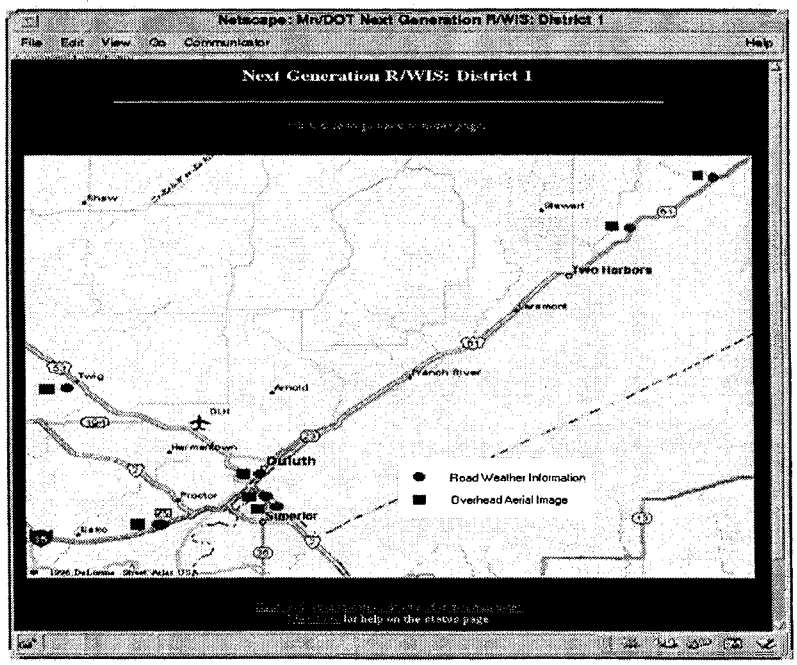


Figure 13: District-1 RPU map.

Figure 14: Aerial image of Silver Cliff RPU site.

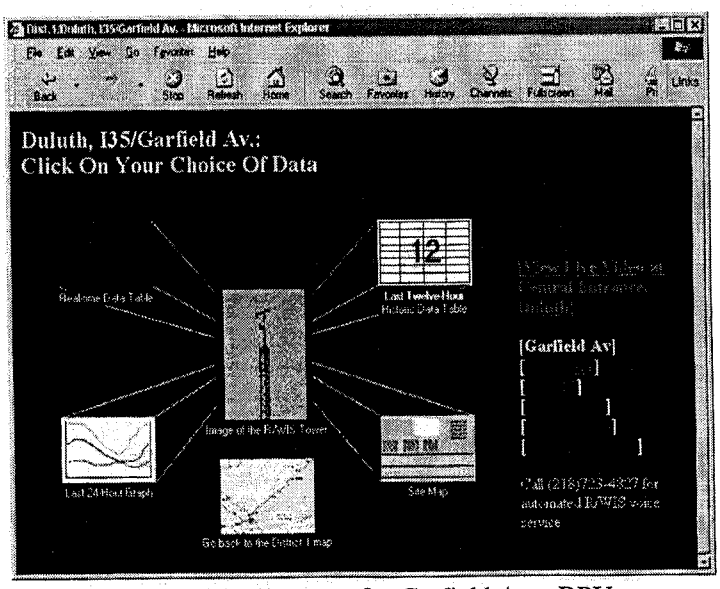


Figure 15: Site menu for Garfield Ave. RPU

From the site menu, the user can choose four different types of data presentations: realtime data table, site map, 24 hour graph, and 12 hour table. The realtime table provides the atmospheric and pavement information of the site that was most recently retrieved from the RPU as a form of tables. Two tables are provided: one table for the atmospheric weather data and the other table for the pavement information. An example taken from the Garfield Ave. site is shown in Figure 16. This realtime data is then transformed into a graphical form called a site map as shown in Figure 17. The site map shows the actual locations of the pavement sensors at the site along with the atmospheric weather and pavement information at that time. The pavement conditions are color coded as the following: Green represents "Dry", "Moist", "Wet", "Wet and Treated"; Yellow represents "Frost"; Red represents "Snow/Ice", and Blue represents "Sensor Short" or "Unknown" conditions. Since all of the pavement conditions can also be read as a text, knowing or memorizing the color code is not that important. The color code was simply applied to give a different level of attention to the users depending on the pavement conditions.

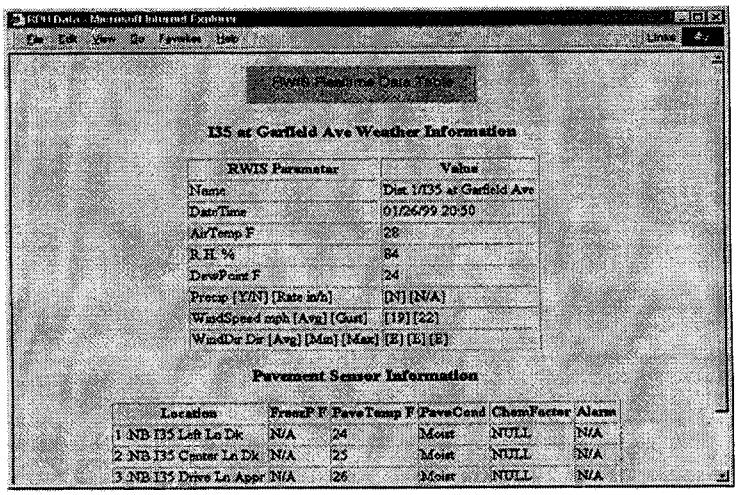


Figure 16: Realtime table from Garfield Ave. Site

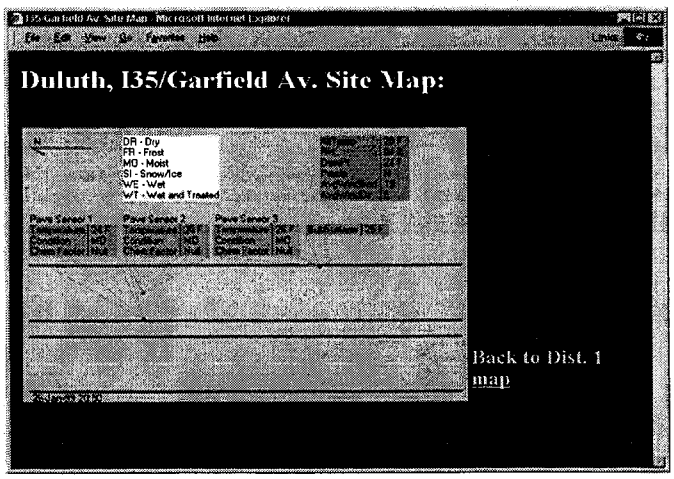


Figure 17: Site map from Garfield Av. Site

Very often understanding the trend of air and pavement temperature along with the dew point is important. For example, if the dew point and air temperature are nearly in a merging state and the pavement temperature falls below the freezing point, frost will be formed on the pavement which is considered hazardous. The 24-hour plot can give information on such trends. Therefore, the web site provides 24-hour realtime plots which are updated every five to ten minutes depending on the site. An example plot is shown in Figure 18. In order to plot the data whenever a new data is inserted into the database, the program utilizes a technique based on a Windows registry for time synchronization between the integration server and database server. The program for generating the 24-hour graphs was completely written in MS Visual Basic 5.0 and Active-X packages. The line graph has limitations in expressing some other types of data, such as wind direction, wind speed, pavement conditions, etc. In order to compensate the additional information to the graph, a 12-hour data table is provided. In this way, the general trend is provided by the 24-hour graph while accurate data instances and pavement conditions are provided in a 12-hour table form. An example of the 12-hour table is shown in Figure 19. The 12-hour table is produced by an SQL trigger whenever a new data is inserted to the corresponding table.

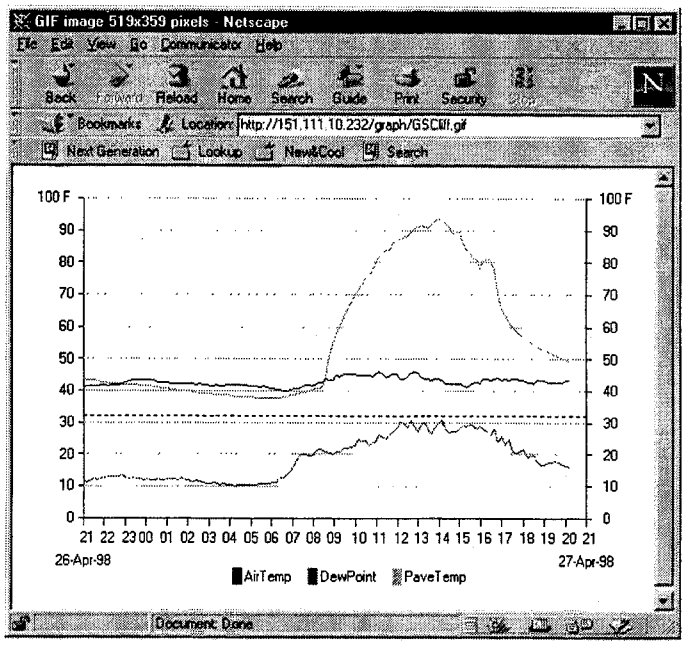
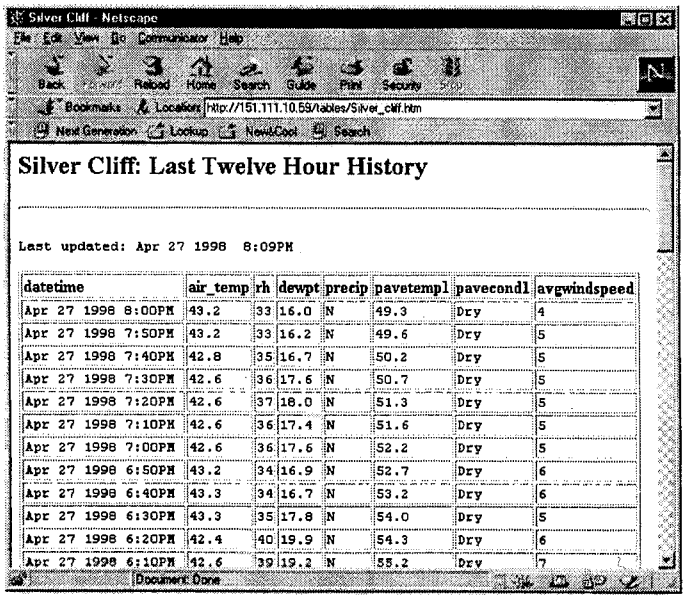


Figure 18: Sample 24-hour graph from Silver Cliff site



datetime	air_temp	rh	dewpt	precip	pavetemp1	pavecond1	avgwindspeed
Apr 27 1998 8:00PM	43.2	33	16.0	N	49.3	Dry	4
Apr 27 1998 7:50PM	43.2	33	16.2	N	49.6	Dry	5
Apr 27 1998 7:40PM	42.8	35	16.7	N	50.2	Dry	5
Apr 27 1998 7:30PM	42.6	36	17.6	N	50.7	Dry	5
Apr 27 1998 7:20PM	42.6	37	18.0	N	51.3	Dry	5
Apr 27 1998 7:10PM	42.6	36	17.4	N	51.6	Dry	5
Apr 27 1998 7:00PM	42.6	36	17.6	N	52.2	Dry	5
Apr 27 1998 6:50PM	43.2	34	16.9	N	52.7	Dry	6
Apr 27 1998 6:40PM	43.3	34	16.7	N	53.2	Dry	6
Apr 27 1998 6:30PM	43.3	35	17.8	N	54.0	Dry	5
Apr 27 1998 6:20PM	42.4	40	19.9	N	54.3	Dry	6
Apr 27 1998 6:10PM	42.6	39	19.2	N	55.2	Dry	7

Figure 19: Sample 12-hour historic data

5.2 Live Video Stream Service

Although video information does not seem directly related to the traditional concept of R/WIS, a close look will immediately reveal that it has a strong tie with any realtime weather information. Suppose that a TV station is reporting about the progress of a big snow storm, flood, or strong winds, what they will show you first would be the video images of the severe weather activities. From these images along with other weather parameters, people can quickly and more accurately assess the situation, and will react accordingly. Also, video information is an excellent source of information for verifying the data received from the environmental sensors and can help assess the details of what has happened as a result of the severe weather. In the author's present view, no other single sensor would be able to replace the capacity of video information.

There are several other important information that can be directly derived from video images in addition to the visual verifications. With recent advances in video processing and computing technologies, many automated detection schemes can be implemented using video images. The following list shows few examples which are presently under research or already developed.

- Visibility can be effectively computed using still video images. This technique has been studied by Kwon [4].
- Blowing and drifting snow can be detected and measured using a motion analysis of sequential frames of the video images.
- Traffic volume and speed can be measured.
- Disastrous conditions such as flood or fire can be detected. This is one of the examples that the traditional R/WIS sensors are not effective, while video images can be very effective.
- Car accidents or severe visible damages of road ways or signs can be detected from video images.

As a general rule, video cameras with the following features are recommended for the R/WIS applications.

- 24-bit color is desirable, but NTSC color would also be acceptable.
- Auto iris function is required to adapt to various lighting conditions. Iris automatically controls the amount of light. It is generally controlled through the exposure time in a CCD camera and a necessary function to acquire a good picture.
- Pixel resolution of 640X480 is considered adequate.
- An automatic back light compensation is necessary in order to minimize any drastic drop of contrast at the objects when the camera is against sunlight.
- During the cold winter or damp summer days, frost or fog on the lens can severely degrade the quality of images. Heaters and cooling fans are required to defrost or defog the camera lens.
- Snow, mud, dust, etc., can severely distort the original image. An automatic cleaning function or a protective mechanism is required to maintain the lens in a clean state.

For this project, a 0.5" color CCD camera (model No. 1335-2000/EH35) made by Cohu Company was installed. The camera was sealed and pressurized in a 3.5" diameter tube of environmental housing. A standard NTSC signal was used. Since the purpose of this project was to demonstrate how video information can be integrated with the traditional weather related R/WIS data, only one camera was installed at the top of the District-1 headquarters building.

The method of video integration chosen for this project was through the Mn/DOT Intranet. Mn/DOT Intranet provides an easy access of information through a well developed infrastructure and is sufficient for the bandwidth requirement of the video stream. Moreover, video information can be easily integrated to a web page and can be viewed using common web browsers.

Presently, many video servers and viewers designed for Internet are available in the market. Most of them are based on compression techniques developed by Motion Picture Experts Group (MPEG) standards. Presently, MPEG I and MPEG II standards are available. The video streams can be live or stored files on demand, and can be viewed by a simple click of mouse .

The system chosen for the video implementation in this project was the Xing Technology Corporation's MPEG live encoder and players. This system can provide both live and on-demand video streams through Internet web browsers and was considered adequate for the present application. The system consists of three parts: an MPEG encoder (hardware), a video server (software) and multiple video players (software). The encoder supplied by the Xing Technology Corporation was a MPEGLive!Encoder. This encoder is a PC box which has a video card and an encoder built into the system. The encoder and video server are separate computer and connected through the Mn/DOT LAN. The video server program is installed in the web server and routs the video streams to the users. The working theory of the overall system is simple. Suppose that the port number of the video server transmitter is 1234, and the port number of the encoder is 6789. When a video player requests video stream, the video server simply reroutes the stream coming from the encoder which is 6789 to the server transmitter port (1234). In order to facilitate this rerouting, the files hyper-linked at the web server must have the encoder port number which is 6789 in this case. For the encoder, it simply needs to know the IP address of the video server. An example image extracted from a live video feed is shown in Figure 20. This image was taken at night and shows the intersection between Garfield Avenue and Central Entrance. One of the characteristics of the video encoders that is more desirable for R/WIS applications is utilizing the bandwidth towards higher quality of pictures than capturing the fast motion. This is because losing few motions is much less significant than losing the quality of the images in maintenance applications. The Xing's MPEGLive!Encoder utilized the available bandwidth towards higher quality than capturing the fast motions.

An informal survey was conducted within District-1 to determine whether prerecorded video images of the road scenes are useful or not. It was found that prerecorded video images are not

of much use unless a significant incident was captured into the video images such as a car accident or a natural disaster. The most value of video was found in a live video feed, from which we can assess the road conditions.

In order to determine what combinations of data give the most useful information, a simple test was conducted using the following method. First, the observer tries to detect the present weather condition such as rain, snow and fog through the Internet video feed only. And then the observer checks the weather conditions using the R/WIS realtime and historic data. The observer draws a conclusion regarding the pavement and weather conditions based on these two sets of data. Next, the observer goes out to the field and verifies his assessment. Similar experiments were conducted using the R/WIS realtime data alone, realtime and historic data, and video data alone. The best assessment of the road conditions was obtained when the realtime data, 24-hour historic data, 12-hour table data, and the live video data were combined. This shows that integrated data is much more effective than any single data alone.

Figure 20: Video image taken from the intersection of Central Entrance and Garfield Avenue, Duluth, Minnesota.

5.3 Automated Voice-Answering Service

The principal idea of relaying the R/WIS information over the phone line through voice is that there is no special skills or computer is required. Anyone who knows how to use a phone can call this user friendly system and obtain the information. For maintenance engineers, this service is very useful when they are working outside their office where they do not have any Internet connection or a computer. Travelers can also use this call service to obtain the R/WIS information for their travel plans.

The phone number presently assigned to this automated voice answering system is (218) 723-4827. From here, we will refer to this automated voice information system as a "voice server." The general operation of this system works as follows. When a user calls the number (218) 723-4827, the voice server detects the ring and enquires the most recent data from the database server. Simultaneously, the voice server side becomes an off-hook state, and a voice menu is played to the caller. The caller makes a selection by pressing one of the touch-tone keys read by the voice menu. The voice server transforms the retrieved R/WIS data to a voice and then plays it to the caller. After sending the data, the voice server repeats the menu again. The caller can quit any time during the phone session by pressing the "*" key or by hanging up. Keeping the spirit of the NG-R/WIS, the system was designed as easy-to-use and user friendly.

The equipment used to develop the automated voice service is as follows:

- *Computer:* Compaq Presario 4504 200 MHz, 16M RAM
- *Modem:* Hayes Accura 336B Data, Fax, and Voice
- *Telephone Line Simulator Hardware:* Skutch Electronics AS-4
- *Telephone Line Simulator Software:* Parity SimPhone
- *Development Software:* Microsoft Visual Basic V5.0
  Parity VoiceBocx
  Parity CallSuite Wizard Add-in

- *Sound Editing Software:* Zentec Vox Studio

For setting up a voice server, a voice modem or a telephony board is required. In addition, Windows TAPI (Telephony Applications Programming Interface) must be installed. In most recent PCs, a version of TAPI is already installed. This is used in conjunction with one or more Microsoft's TSPs (Telephone Service Providers). Most systems running under Windows will have the Microsoft Unimodem TSP which was the case in our system. The software Simphone provided by Parity software can be used for recording and playing back sound files. Obviously, a sound card, a microphone, and speakers are needed. Also, the sound card must have a WAVE driver.

The standard sound format used in Windows is the WAVE format which is identified by the ".wav" file extension. It is most commonly recorded at a 16-bit, 11 kHz sampling rate, but can also be in other formats which have higher quality but more memory requirements. There is another family of schemes known as ADPCM (Adaptive Differential Pulse Code Modulation), which is frequently used in voice processing hardware. The ADPCM sound format that most telephony cards use is called VOX (from the Latin work "vox" which means "voice") and is identified by the ".vox" file extension. VOX files are not compatible with the Windows WAVE files. VOX files are usually in a 4 bit, 6 KHz configuration which is the case of the sound files in this project. There is no file header for its sample size and sampling rate like there is in a WAVE file.

When working on the application from the CallSuite Wizard Add-in, the files are recorded from the microphone attached to the sound card using SimPhone and are immediately converted into VOX format as they are being recorded. This is what was used to create the longer phrases used in the voice server. For the shorter little variable words like "One", "Monday", "April", and "Dollars", we used the VOX studio software to do the recording. VOX Studio has the capability to record sound files in WAVE format and convert them into VOX format. We only used the trial version so sound files were restricted to five seconds in length. First the sound was record with

the microphone and saved in the standard wave format. Then the current file is converted into a Dialogic, 4-bit ADPCM, 6 KHz format and saved with a ".vox" extension. In general, the WAVE format has much better sound quality.

Short variable words and phrases are used in TTS (Text to Speech) conversion which is the process of generating spoken phrases from input text. There are a couple main types of phrases that can be played by the built in features of VoiceBocx.

- Numbers: 2538 —> "Two Thousand Five Hundred Thirty Eight"
- Ordinals: 61 —> "Sixty First"
- Money: $72.01 —> "Seventy Two Dollars And One Cent"
- Dates: 19980103 —> "January Third Nineteen Ninety Eight"
- Times: 1336 —> "One Thirty Six PM"
- Strings: 12o#p —> "One Two Oh Pound Pee"

All of these little sound files are put into another type of sound file called an Indexed Prompt File (IPF). An IPF is a collection of VOX files combined into a large single file. IPFs are read only and cannot be edited. If one tries to edit the sound files in an IPF, it would start creating small wasted spaces by replacing a longer file with a shorter one and would write over some of the next sound by replacing a smaller file with a larger one. The alternative would be to have a lot of overhead to handle the re-organizing of the IPF. In order to edit the whole sound files in the existing IPF files (Stan24ke.ipf and STdt24ke.ipf), the utilities "expipf.exe" and "mkipf.exe" are used. "Expipf.exe" breaks the IPF file into separate editable VOX files and "Mkipf.exe" takes a group of VOX files defined by the header file and makes an IPF file out of them.

In order to test the application during the development stage, a telephone simulator called SimPhone is used. It is as simple as moving the mouse to the ring button once the application has started and then to the desired buttons for the menu options. Everything from each procedure can be heard through the speakers connected to the sound card. The main features of SimPhone

include:

- Projects can be developed without having all of the necessary hardware to actually run it. It can be saved on a disk and put on a computer that has a Dialogic board or voice modem installed to run the project.
- Projects can be easily demonstrated to others without requiring an actual call.
- It supports VOX format unlike the other sound players that run in a Windows environment. When an application is running, it can play and record VOX files through a WAVE compatible sound card.
- VoiceBocx and SimPhone were designed to work together so the same program can be run on an actual phone line or on Simphone without changing settings. It will automatically adjust to work on the simulated line.

SimPhone must be started before the application is started in order for it to be recognized. In a Visual Basic development environment, Simphone can be started by clicking on the Simphone option under the add-ins menu. It does not need to be started before starting Visual Basic itself. When there is no current telephony application running, the Ring command button will be greyed out. That way the ring signal cannot be sent to a program that does not exist. Once an application has started, the Ring button becomes enabled. The telephone icon shows whether or not the phone line is open or closed. The phone on-hook declares a closed line. Once the phone is off-hook, the ring button turns into a hang-up button. Clicking on this will then simulate a disconnection. Clicking on any of the numerals will put that digit on the simulated channel. SimPhone is nice for developing and demonstrating, but testing with a real phone line is the only way that can ensure that the application runs correctly. For the development of software, CallSuite Wizard can be used as the first step to generate an initial template, and then Visual Basic codes can be added to complete the software. Figure 21 shows the state diagram of the program developed and summarizes how the overall program works. Programming techniques are further explained in Appendix E.

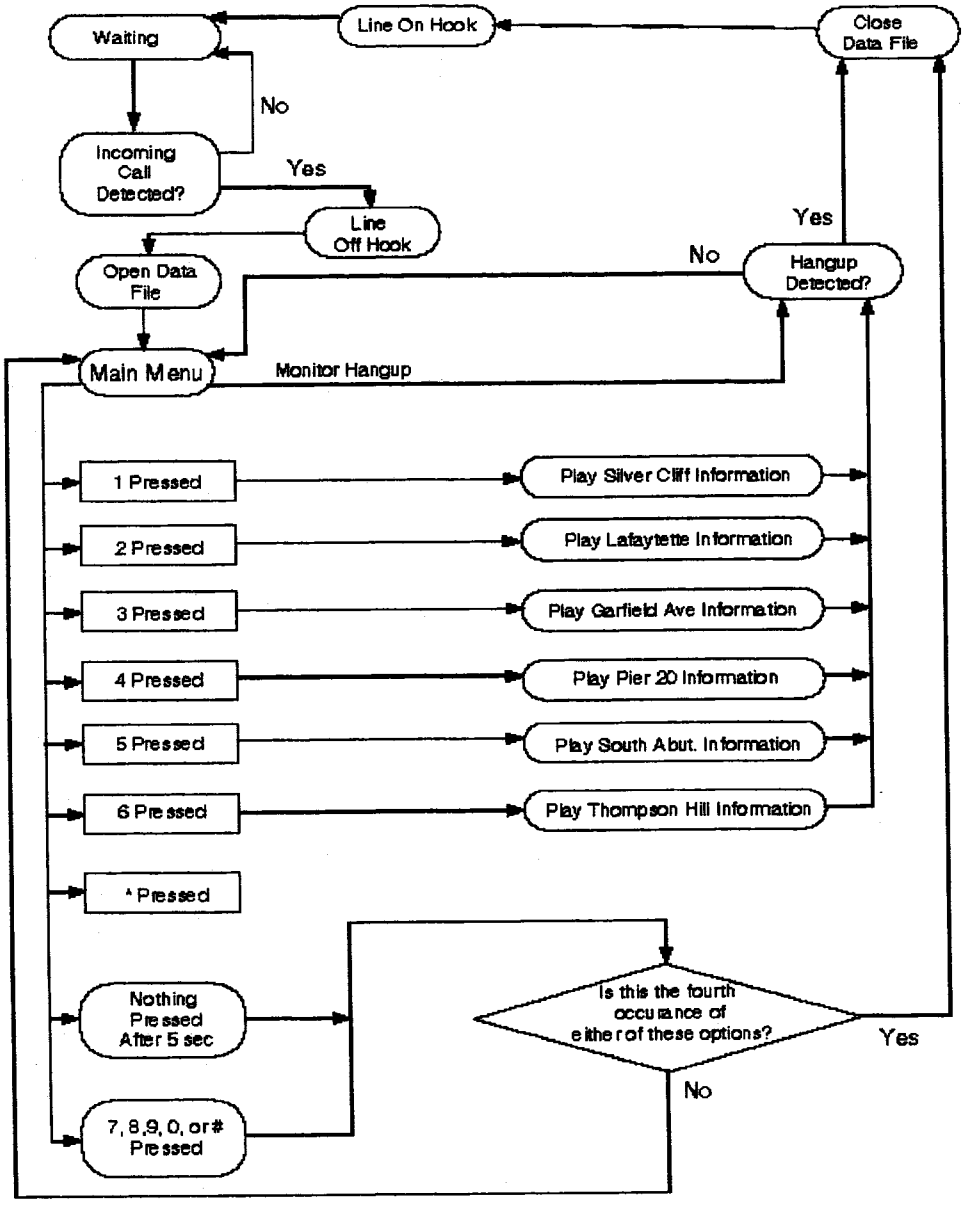


Figure 21: Flow graph of voice server program

6 PROJECT EVALUATION

Implementation of all four layers of NG-R/WIS was completed at the end of April 1998 for demonstration and evaluation. On May 12, 1998, Mr. Ed Fleege at Mn/DOT organized a meeting to evaluate and make suggestions for the NG-R/WIS project. The members who participated in the meeting consisted of five Mn/DOT engineers and decision makers and four UMD students participated in the projects and the project leader Dr. Taek Kwon.

The participants are:

Mn/DOT

Ed Fleege
Bruce Larson
Dean Cummins
Roberta Dwyer
Jay Koski
Lauraine Cramer

UMD

Taek Kwon
Mark Sholund
Scott Findley
Erik VanGuilder
Andy Olson

The meeting started by introducing the project background and overview by Dr. Taek Kwon. Mr. Bruce Larson described the past state of the R/WIS at Mn/DOT District-1 and summarized his view on the project. He further summarized the general evaluation of Mn/DOT regarding the work result as:

"The overall project exceeded our expectation."

Mr. Ed Fleege went through the web pages one by one using a screen projector and asked suggestions on what could be improved at the user interface end. The following summarizes the list of suggestions that came out of the evaluation meeting.

Main and District-1 Map pages

- The "Modem and Site Status" link is difficult to understand. Provide "a help page" in describing the meaning of this page. Also, password protection may be needed.
- Change the color of the main page on video indicators, so that it stands out.
- Per district-1 map, provide pop-up labels at each RPU location for the identification purpose of the site.
- From the aerial photo, make the site names standout by writing the letter on a high contrast background stripe.

Realtime Data Table

- Spell out Yes/No instead of using Y/N.
- For wind direction, use a cardinal notation, i.e., N, NE, SE, ... etc.

Site Map

- Have color change to reflect the pavement condition.
- Use light blue background instead of blue background for atmospheric data.
- Correct the sensor locations.
- Make the site map be the first page to access from the Dist-1 map.
- Add a menu to the site map to lead to other pages.
- Label sensors on the site map.

- Per RPU towers, provide a narrative paragraph.
- Remove the password requirement from the realtime table.
- Correct the arrows in the aerial photo. Do not use the word RPU on the label.

Live Video Stream

No suggestions were received.

Automated Voice Service

- Add wind direction information.

These suggestions were carefully reviewed and reflected to the design of the overall application layer. At the end of the meeting, Dr. Kwon distributed a survey questionnaire to all Mn/DOT members in the meeting to further evaluate and probe the present work. Only one person replied to the questionnaire due to limited time. The questionnaire is attached in Appendix F.

7 CONCLUSIONS

7.1 Future Work and Recommendation

This project merely developed and demonstrated a new concept and architecture from the existing R/WIS that could grow with new technologies and applications. The emphasis of the architecture was given to the development of the integration and dissemination infrastructures to improve the main deficiency of the present system. However, there is still more work to be done than what has already been done in order to achieve the full benefit of the proposed NG-R/WIS. Several issues on future work and recommendations of the author's opinion are discussed here.

Presently, no standards exist in the data integration layer of the NG-R/WIS. Due to this absence, it is very difficult to add new sensors to or remove the old ones from the existing RPUs and integration servers unless the integrator is the original manufacturer of the units. It is desirable that RPUs be designed, such that they follow a standard programmable environment from which users can easily add, remove, or modify the sensors connected to RPUs. Therefore, it is recommended that Mn/DOT establishes a standard for the data integration layer.

Present implementation of web pages simply provide a pool of general information, from which everybody sees the same data. This application can be further developed into a new technology called "push technology" which provides customized information to each individual or group of people instead of providing the same information to everybody. This application could be integrated with the technology called data mining[1] in order to extract the information needed for specific users or groups from the central database and process them to meet the customized needs. Along with this, automated emails or paging systems could be easily developed from the present NG-R/WIS to supplement the use of web pages.

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[1]Data mining is a term used to describe "data-driven discovery of trends and relations in archival data."

Although sensor technologies have been steadily improving during the last decade or so due to the rapid evolution in digital technologies, several critically important sensors for road information have yet to be developed. These include sensors that could measure the amount of snow on the road, slipperiness of the pavement, and visibility in blowing snow. In particular, there is a need for developing a method or a sensor that could measure how much snow is on the road, because if the amount of snow is known, it is then possible to calculate how much salt would be required to melt the snow under the given pavement temperature. Such information could significantly reduce the amount of salt used and will lead to huge savings in snow removal cost, minimum damage to the environment, and increased efficiency of the snow removal operations. Unfortunately, present R/WIS sensors can not detect how much snow is actually on the road surface, although it may detect the existence and the rate of fall. Therefore, it is recommended that some research work should be done to develop a new sensor for snow measurements. Next, information on the slipperiness of a road surface is equally important for road maintenance and driver safety, because it provides a feedback to the maintenance engineers on how much they have to improve the traction of the road surface, and because it provides an early warning to the public for precaution. Presently, slipperiness of road surface can be measured, but the equipment available is too expensive for use in practice. Consequently, most states do not measure the slipperiness of the road. Therefore, a large effort in developing a low-cost slipperiness sensor is needed and is recommended for future research work.

National Weather Service provides excellent data for the present and forecasted weather. This information is extremely valuable for predicting the pavement conditions and have been used by Mn/DOT maintenance engineers. Therefore, it is recommended that the National Weather Service data be integrated with the existing R/WIS and disseminated through the web pages.

Snow storms and related bad pavement conditions are one of the leading causes of traffic disruption in Minnesota. One of the purposes of winter road maintenance is to provide good driving conditions for travelers, such that traffic flows smoothly and accidents are minimized.

Therefore, there is a need for an integrated treatment of the R/WIS data, the traffic management strategy, and the snow removal operations. For example, if the pavement traction of an intersection was significantly reduced due to snow and ice on the ground, each phase of the traffic control signal should be extended to compensate the slow response time. If, however, the pavement condition was improved due to the maintenance operation, the control logic should be operated back to a normal mode. Such an adjustment of the traffic control according to the pavement condition has not been employed in Minnesota. Therefore, it is recommended that the traffic and incident data be integrated with the R/WIS data, such that both traffic and maintenance engineers have a better understanding on how each side affects and benefits by coordinating their operations.

The R/WIS database provides a set of road conditions and forecasts which could be extremely beneficial to travelers. Such information can be easily customized for travelers from the present R/WIS architecture and provided to the public in the form of web pages. Going one step further, if the road conditions become hazardous to drive, variable message signs could be used to warn the public based on the realtime information available from the NG-R/WIS database. Therefore, development of a travelers information system that incorporates the NG-R/WIS information is recommended.

When a snowstorm occurs, travelers not only need to know the amount of snow fall, but also when the road was last plowed in order to assess their journey. Therefore, there is a need for creating a snowplow information network (SIN) that could report snow removal activities to the public in realtime. Creating such a network and integrating it as a part of R/WIS will benefit both travelers and snow removal operators. Travelers would get information on which roads are cleared, while the maintenance engineers will get information on which road needs to be cleared. Therefore, development of a SIN is recommended.

In R/WIS, the sensor data at each RPU only represents a sample along a long stretch of the road. In many cases the distance between RPUs could exceed more than 100 miles, and the weather

and pavement data between the RPU sites could be significantly different from the RPU sites. Therefore, there is a need for mathematically estimating the data between RPUs where sensors are not available. Such a technique is called a now-forecast and requires a mobile sensor vehicle in order to collect sample data between the RPU sites. The historical data collected from each RPU site and the mobile sample of data along the stretch of the road provide the two essential components needed for the now-prediction. Another component suggested by many researchers is the inclusion of geographical characteristics along the stretch of the road such as rock-cut, vegetation area, etc. to increase the forecast accuracies [2]. It is recommended that Mn/DOT incorporates now-prediction as a basic function of the R/WIS.

Other future works recommended include an automated pager system that calls maintenance engineers to the affected area, AM/FM radio broadcast system for data dissemination, crew scheduling and decision support system, automated incident detection and monitoring, and video integration at RPU sites.

7.2 Conclusions

The original R/WIS in the Mn/DOT District 1 office consisted of equipment from three different manufacturers and had a number of problems that made it difficult for users to access and use the system. This project recognized those problems and set out to provide solutions. In addition, this project was intended to build a system that could serve as a prototype for the newly initiated statewide R/WIS project. The immediate goals were developing a system that is easy to use, allows unlimited access from anywhere, provides unified data format, requires neither special terminals nor software, and has an architecture that is scalable and easy to integrate. In order to achieve these goals, a new concept of layered architecture called the Next-Generation R/WIS was introduced and implemented. This architecture allowed integration of heterogeneous systems through the data integration layer and provided structured data to applications through a standard relational database. Three applications were developed in this project: web page service,

automated voice service, and live stream-video service. The data dissemination method through web pages and automated voice services provided the solutions for the design goals of unlimited access from anywhere, unified format, ease of use, and no requirements of special terminals or software. The live video-stream service demonstrated integration capability of the system and provided a new class of information. According to the comments from the evaluation meeting, the project was successfully completed and exceeded the Mn/DOT's expectation.

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Appendix A

Sensor Data Available from District-1 RPU Sites

Appendix A: Sensor Data Available from District-1 RPU Sites

A.1 SSI RPUs

SSI RPUs are installed at the following sites: Lafayette Bluff, Garfield Av. Duluth, and Thompson Hill. Atmospheric and pavement data are available from all sites and summarized below.

A.1.1 Atmospheric Data

(1) *Air Temperature:* Degrees in Fahrenheit

(2) *Wind Direction:* Min, Avg, Max in 0 to 360 Degrees

(3) *Wind Speed:* Avg, Gust in Miles per Hour

(4) *Relative Humidity:* Percent

(5) *Dew Point Temperature:* Degrees in Fahrenheit

(6) *Precipitation:* [Y/N]

(7) *Precipitation Type and Intensity:* Not available from District-1 installation, WIVIS must be installed.

(8) *Precipitation Rate:* Not available from District-1 installation, WIVIS must be installed.

(9) *Daily Precipitation Accumulation:* Not available from District-1 installation, WIVIS must be installed.

A.1.2 Pavement Data

A.1.2.1 Surface Sensor

(1) Status:

Dry

Wet

Chemical Wet:

Precipitation occurring, moisture present on the surface, and surface temperature at or below 32 degrees Fahrenheit.

Snow/Ice Alert:

Precipitation occurring, moisture in liquid form on the surface starting to freeze. Precipitation occurring, moisture on the surface which has frozen.

Absorption:

Moisture present on surface in an insufficient amount to present a hazard and no precipitation is present.

Dew:

Moisture present on surface, no precipitation , surface temperature is equal to or less than dew point, and surface temperature is above 32 degrees.

Frost:

No precipitation, surface temperature moving through dew point, and surface temperature is below 32 degrees.

Absorption@Dpt:

Moisture present on surface in an insufficient amount to present a hazard, dew point has been reached, and no precipitation is present.

(2) Surface Temperature: Degrees in Fahrenheit

(3) Chem Factor: Percent

A.1.2.2 Sub-Surface Sensor

(1) Temperature: Degrees in Fahrenheit

A.2 Vaisala RPUs

Vaisala RPUs are located at the following sites: Pier 20 and South Abutment of Blatnik Bridge and Thompson Hill. Atmospheric and pavement data are available from all sites and summarized below.

A.2.1 Atmospheric Data

(1) *Air Temperature:* Degrees in Fahrenheit

(2) *Relative Humidity:* Percent

(3) *Dew Point:* Degrees in Fehrenheit

(4) *Precipitation Type:*

H: Heavy, above 8 mm per hour

M: Medium, 2-8 mm per hour

L: Light, 0-2 mm per hour

R: Rain, precipitation reported at the time of observation

r: Recent rain, precipitation recorded between the last observation and this observation.

(5) *Precipitation Rate:* Inches per Hour

(6) *Wind Direction:* 0 to 360 Degrees

(7) *Wind Speed:* Avg and Gust peed in miles per hour.

A.2.2 Pavement Data

(1) *Pavement Temperature:* Degrees in Fahrenheit

(2) *Soil Temperature:* Degrees in Fahrenheit

(3) *Freezing Point:* Degrees in Fahrenheit

(4) *Surface Status:*

DR: Dry

MO: Moist

WE: Wet

TR: Trace, residual chemical on surface

WT: Wet and Treated, surface wet and deicing chemical present

FR: Frost

SN: Snow

IC: Ice

SH: Sensor short, short circuit perhaps due to cable fault

Appendix B

Extraction of Data from Vaisala and SSI RPU Servers

Appendix B: Extraction of Data from Vaisala and SSI RPU Servers

The integration server polls the Vasala and SSI RPU severs every three minutes through modem. Since both RPU servers are designed to work with terminals, it sends out terminal control characters which are mixed with the data we need. This appendix describes how the data are extracted.

B.1 Vaisala Data

Through a terminal capture function, Vaisala server data is captured into a file where extra control characters are mixed with the R/WIS data. This data represents the formatting codes sent to the screen to make the display easy to read. This additional data just gets in the way of extracting the relevant data and must be removed before data extraction can take place.

The formatting codes all begin with an escape character ("[redacted]" in a text display) and end with the letter "H". The raw data file is sent to a Visual Basic procedure Character_Remove() which writes each character from the raw data file to a new file but excludes all characters between and including the beginning escape character and ending "H". This new file contains the information shown in Figure 6 in a non formatted form with a few additional strings intermixed. The process of extracting data from each of the three sites is the same, with the Silver Cliff data provided as an illustration.

The first bit of useful information is the name of the site, TH61 Silver Cliff, but this is preceded in the capture file by some useless data. This data contains two occurrences of the string (characters between spaces) "STATUS", so it is a simple matter of getting a string, checking to see if it is "STATUS", and then stopping when "STATUS" is encountered the second time. This second occurrence is the "STATUS" seen at the top of Figure 6. The current string now

contains "SITESTATUSTH61SilverCliffDATA". The name of the site imbedded in this string is determined by comparing it with the string "Silver" and "Pier". If it is not one of these two, it is interpreted as the third site name.

The second piece of information is the time. This is extracted by skipping the next string and reading the following string into a variable. The date follows immediately after this is written to a variable. All data starting from "CDT" to "#1" is skipped and the air, soil, and freezing point temperatures are read into their respective variables. The next string is examined to see if it starts with a digit. This produces two cases with different results:

1 It is a digit. "N" is written to the precipitation variable and the current string is written to the precipitation rate variable.

2. It is not a digit. The character in the current string is written to the precipitation variable and the next string is read and written to the precipitation rate variable.

The wind direction (0° to 360° with 0° being a wind from the north, 90° being from the east and so on), average wind speed, and wind gust speed are written to their respective variables.

Data is skipped to reach the name of the first pavement sensor, here the string "NB". This, and all subsequent strings, are written as an entry into an array of pavement names until the current string contains a period. This indicates that data is encountered and the pavement, soil, and freezing point temperatures are read and written into variables. Then the pavement condition code is written to a variable. If only one character appears in the next string, then it is an alarm code that is then written to an array. This step is repeated until all of the pavement information is read. Here, three more lines of data must be interpreted. When all of the data for the pavement sensors are contained in variables, all of the data collected for the site can be written to a table in an SQL database. As a final step before proceeding to the remain sites, an HTML (HyperText Markup Language) file is written in which all of this data is presented in a table. With all of the data recorded, the process of reading and writing data is repeated for the two

remaining Vaisala sites (Pier 20 on the Blatnik Bridge and Blatnik Bridge's South Abutment).

B.2 SSI Data

Unlike Vaisala, the data in Figure 10 does not contain formatting codes that appear when that data is captured. The removal of extra data is not necessary.

The first step to interpreting data SSI data is to get the name of the site that is being scanned. This is accomplished by looking for a string in the format MM/DD/YY. This will read and skip every string up to the "Power on" date. The name of the site is then read into a string variable until "RPU" is encountered. The next piece of information is the time. This can be found by looking for a string of the format HH:MM and the data we want follows.

The next piece of data we want to read is the air temperature. This can be found by looking for a string that has a digit as the first character. In Figure 10, 63 is the air temperature and is read into a variable. The dew point is then read in the same fashion. The precipitation indicator is either "Y" or "N" indicating whether or not precipitation is currently falling. The relative humidity is read as the next number and then the data becomes a bit tricky. Two cases now arise:

1. It is a calm day. No wind directions will be shown. For our program to work correctly however, a wind direction must always be given so we set the three directions variables to 0°. The Average Wind Speed, "Calm", is converted to 0 mph and the Gust Wind Speed is read. If that is a number, everything is okay, but if it is "Calm" as well, then it is converted to 0 mph also.
2. It is a windy day. This is a different case than the figure shows, but it occurs nonetheless. The three wind directions are read as one of eight cardinal direction strings (N, NE, E, SE, S, SW, W, or NW) and each is converted to an angle (0°, 45°, 90°, 135°, 180°, 225°, 270°, 315°). Since a definite wind direction exists,

there will be average and gust wind speeds.

Now a series of pavement sensors providing a name, condition, temperature, and chemical factor must be read. The first sensor's name can be reached by reading strings until a number is found. This will position the file pointer right before the next pavement sensor. Strings are read and added to the sensor name until a known pavement condition is reached. This condition must be converted to a meaningful value and the next string can be read as the temperature at that sensor. Now the chemical factor must be read, but one might not be present. The way to remedy this is to assume that one exists, read it as the chemical factor and then look at the next string. If the next string is not a digit, then no chemical factor exists. Set the chemical factor to "NULL" to reflect this. This procedure is done for the rest of the pavement sensors until the "Sub-Surface Temperature" string is found; only a temperature is read. The sensor station is now completely interpreted. The data from this site can be written to a database and the remaining two sites (one on Thompson Hill in Proctor, MN and one at the "intersection" of Interstate 35 and Garfield Avenue in downtown Duluth) are examined using the same procedure.

Appendix C

SQL Scripts for Table Creation

Appendix C: SQL Scripts for Table Creation

```
/* Microsoft SQL Server - Scripting                */
/* Server: D1ANTS060                               */
/* Database: rwis                                  */
/* Creation Date 12/8/98 4:38:20 PM                */

/****** Object:  Table dbo.garfield    Script Date: 12/8/98 4:38:21 PM ******/
CREATE TABLE dbo.garfield (
        datetime datetime NOT NULL ,
        air_temp real NOT NULL ,
        rh tinyint NOT NULL ,
        dewpt real NOT NULL ,
        precip char (1) NOT NULL ,
        avgwindspeed int NOT NULL ,
        gustwindspeed int NOT NULL ,
        avgwinddir int NULL ,
        minwinddir int NULL ,
        maxwinddir int NULL ,
        pavetemp1 real NOT NULL ,
        pavetemp2 real NOT NULL ,
        pavetemp3 real NOT NULL ,
        pavetemp4 real NOT NULL ,
        pavecond1 char (15) NOT NULL ,
        pavecond2 char (15) NOT NULL ,
        pavecond3 char (15) NOT NULL ,
        pavechem1 int NULL ,
        pavechem2 int NULL ,
        pavechem3 int NULL
```

```
GO

/****** Object:  Trigger dbo.Web_367704758_1    Script Date: 12/8/98 4:38:21 PM ******/
CREATE TRIGGER Web_367704758_1 ON dbo.garfield FOR INSERT AS
begin
  exec sp_makewebtask @outputfile='C:\InetPub\wwwroot\tables\garfield.htm',@query='select
a.datetime, a.air_temp, a.rh, a.dewpt, a.precip, a.avgwindspeed, a.pavetemp1, a.pavecond1,
a.pavechem1 from rwis.dbo.garfield a where datetime > dateadd(hour,-12,getdate()) order by
datetime
desc',@fixedfont=1,@bold=0,@italic=0,@colheaders=1,@lastupdated=1,@HTMLheader=2,@u
sername='dbo',@dbname='rwis',@webpagetitle='SQL Server Web Assistant',@resultstitle='I35@
Garfield Av: Last Twelve Hour History',@maketask=0,@rowcnt=0
end
GO

/* Microsoft SQL Server - Scripting                */
/* Server: D1ANTS060                               */
/* Database: rwis                                  */
/* Creation Date 12/8/98 4:37:51 PM                */

/****** Object:  Table dbo.lafayette    Script Date: 12/8/98 4:37:51 PM ******/
CREATE TABLE dbo.lafayette (
        datetime datetime NOT NULL ,
        air_temp real NOT NULL ,
        rh tinyint NOT NULL ,
        dewpt real NOT NULL ,
        precip char (1) NOT NULL ,
        avgwindspeed int NOT NULL ,
```

```
    gustwindspeed int NOT NULL ,
    avgwinddir int NULL ,
    minwinddir int NULL ,
    maxwinddir int NULL ,
    pavetemp1 real NOT NULL ,
    pavetemp2 real NOT NULL ,
    pavetemp3 real NOT NULL ,
    pavetemp4 real NOT NULL ,
    pavecond1 char (15) NOT NULL ,
    pavecond2 char (15) NOT NULL ,
    pavecond3 char (15) NOT NULL ,
    pavechem1 int NULL ,
    pavechem2 int NULL ,
    pavechem3 int NULL

GO


/****** Object:  Trigger dbo.Web_399704872_3    Script Date: 12/8/98 4:37:52 PM ******/
CREATE TRIGGER Web_399704872_3 ON dbo.lafayette FOR DELETE AS
begin
  exec sp_makewebtask @outputfile='C:\InetPub\wwwroot\tables\lafayette.htm',@query='select
a.datetime, a.air_temp, a.rh, a.dewpt, a.precip, a.avgwindspeed, a.pavetemp1, a.pavecond1,
a.pavechem1 from rwis.dbo.lafayette a where datetime > dateadd(hour,-12,getdate()) order by
datetime
desc',@fixedfont=1,@bold=0,@italic=0,@colheaders=1,@lastupdated=1,@HTMLheader=2,@u
sername='dbo',@dbname='rwis',@webpagetitle='SQL Server Web
Assistant',@resultstitle='Lafayette Bluff: Last Twelve Hour History',@maketask=0,@rowcnt=0
end
```

```
GO

/* Microsoft SQL Server - Scripting                */
/* Server: D1ANTS060                               */
/* Database: rwis                                  */
/* Creation Date 12/8/98 4:37:11 PM                */

/****** Object:  Table dbo.pier_20    Script Date: 12/8/98 4:37:12 PM ******/
CREATE TABLE dbo.pier_20 (
        datetime datetime NOT NULL ,
        air_temp real NOT NULL ,
        rh tinyint NOT NULL ,
        dewpt real NOT NULL ,
        precip char (1) NOT NULL ,
        prate real NULL ,
        avgwinddir int NULL ,
        avgwindspeed int NOT NULL ,
        gustwindspeed int NOT NULL ,
        pavetemp1 real NOT NULL ,
        pavetemp2 real NOT NULL ,
        soiltemp1 real NOT NULL ,
        soiltemp2 real NOT NULL ,
        freeze1 real NULL ,
        freeze2 real NULL ,
        pavecond1 varchar (15) NOT NULL ,
        pavecond2 varchar (15) NOT NULL ,
        alarm1 char (1) NULL ,
        alarm2 char (1) NULL
```

```
GO

/****** Object:  Trigger dbo.Web_416004513_1    Script Date: 12/8/98 4:37:14 PM ******/
CREATE TRIGGER Web_416004513_1 ON dbo.pier_20 FOR INSERT AS    begin    exec
sp_makewebtask @outputfile='C:\Inetpub\wwwroot\tables\pier_20.htm',@query='select
datetime,  air_temp,rh,dewpt,precip, pavetemp1,pavecond1,avgwindspeed from pier_20 where
datetime > dateadd(hour, -12, getdate()) order by datetime
desc',@fixedfont=1,@bold=0,@italic=0,@colheaders=1,@lastupdated=1,@HTMLheader=2,@u
sername='dbo',@dbname='rwis',@webpagetitle='Pier 20, Blatnik',@resultstitle='Pier 20, Blatnik:
Last Twelve Hour History',@maketask=0,@rowcnt=0  end

GO

/* Microsoft SQL Server - Scripting                */
/* Server: D1ANTS060                               */
/* Database: rwis                                  */
/* Creation Date 12/8/98 4:36:24 PM                */

/****** Object:  Table dbo.s_abut    Script Date: 12/8/98 4:36:24 PM ******/
CREATE TABLE dbo.s_abut (
        datetime datetime NOT NULL ,
        air_temp real NOT NULL ,
        rh tinyint NOT NULL ,
        dewpt real NOT NULL ,
        precip char (1) NOT NULL ,
        prate real NULL ,
        avgwinddir int NULL ,
        avgwindspeed int NOT NULL ,
```

```
    gustwindspeed int NOT NULL ,
    pavetemp1 real NOT NULL ,
    pavetemp2 real NOT NULL ,
    pavetemp3 real NOT NULL ,
    soiltemp1 real NOT NULL ,
    soiltemp2 real NOT NULL ,
    soiltemp3 real NOT NULL ,
    freeze1 real NULL ,
    freeze2 real NULL ,
    freeze3 real NULL ,
    pavecond1 varchar (15) NOT NULL ,
    pavecond2 varchar (15) NOT NULL ,
    pavecond3 varchar (15) NOT NULL ,
    alarm1 char (1) NULL ,
    alarm2 char (1) NULL ,
    alarm3 char (1) NULL

GO


/****** Object:  Trigger dbo.S_Abut1    Script Date: 12/8/98 4:36:25 PM ******/
CREATE TRIGGER S_Abut1 ON dbo.s_abut FOR INSERT AS  begin     exec sp_makewebtask
@outputfile='C:\InetPub\wwwroot\tables\South_Abut.htm',@query='select datetime, air_temp,
rh, dewpt, precip, pavetemp1, pavecond1, avgwindspeed  from S_Abut where datetime >
dateadd(hour, -12, getdate()) order by datetime
desc',@fixedfont=1,@bold=0,@italic=0,@colheaders=1,@lastupdated=1,@HTMLheader=2,@u
sername='dbo',@dbname='rwis',@webpagetitle='Blatnik S. Abut',@resultstitle='Blatnik S. Abut:
Twelve Hour History',@maketask=0,@rowcnt=0  end
```

```
GO

/* Microsoft SQL Server - Scripting                */
/* Server: D1ANTS060                               */
/* Database: rwis                                  */
/* Creation Date 12/8/98 4:09:21 PM                */

/****** Object:  Table dbo.silver_cliff    Script Date: 12/8/98 4:09:22 PM ******/
CREATE TABLE dbo.silver_cliff (
        datetime datetime NOT NULL ,
        air_temp real NOT NULL ,
        rh tinyint NOT NULL ,
        dewpt real NOT NULL ,
        precip char (1) NOT NULL ,
        prate real NULL ,
        avgwinddir int NULL ,
        avgwindspeed int NOT NULL ,
        gustwindspeed int NOT NULL ,
        pavetemp1 real NOT NULL ,
        pavetemp2 real NOT NULL ,
        pavetemp3 real NOT NULL ,
        pavetemp4 real NOT NULL ,
        soiltemp1 real NOT NULL ,
        soiltemp2 real NOT NULL ,
        soiltemp3 real NOT NULL ,
        soiltemp4 real NOT NULL ,
        freeze1 real NOT NULL ,
        freeze2 real NOT NULL ,
        freeze3 real NOT NULL ,
```

```
    freeze4 real NOT NULL ,
    pavecond1 varchar (15) NOT NULL ,
    pavecond2 varchar (15) NOT NULL ,
    pavecond3 varchar (15) NOT NULL ,
    pavecond4 varchar (15) NOT NULL ,
    alarm1 char (1) NULL ,
    alarm2 char (1) NULL ,
    alarm3 char (1) NULL ,
    alarm4 char (1) NULL

GO


/****** Object:  Trigger dbo.Web_368004342_1    Script Date: 12/8/98 4:09:22 PM ******/
CREATE TRIGGER Web_368004342_1 ON dbo.silver_cliff FOR INSERT AS    begin    exec
sp_makewebtask @outputfile='C:\Inetpub\wwwroot\tables\silver_cliff.htm',@query='select
datetime,  air_temp,rh,dewpt,precip, pavetemp1,pavecond1,avgwindspeed from silver_cliff
where datetime > dateadd(hour, -12, getdate()) order by datetime
desc',@fixedfont=1,@bold=0,@italic=0,@colheaders=1,@lastupdated=1,@HTMLheader=2,@u
sername='dbo',@dbname='rwis',@webpagetitle='Silver Cliff',@resultstitle='Silver Cliff: Last
Twelve Hour History',@maketask=0,@rowcnt=0  end

GO
/* Microsoft SQL Server - Scripting                */
/* Server: D1ANTS060                               */
/* Database: rwis                                  */
/* Creation Date 9/22/98 1:14:04 PM                */
/* This is to rebuild the thompson table           */
```

```
use rwis
GO


/****** Object:  Table dbo.thompson    Script Date: 9/22/98 1:14:05 PM ******/
CREATE TABLE dbo.thompson (
        datetime datetime NOT NULL ,
        air_temp real NOT NULL ,
        rh tinyint NOT NULL ,
        dewpt real NOT NULL ,
        precip char (6) NOT NULL ,
        avgwindspeed int NOT NULL ,
        gustwindspeed int NOT NULL ,
        avgwinddir int NULL ,
        minwinddir int NULL ,
        maxwinddir int NULL ,
        pavetemp1 real NOT NULL ,
        pavetemp2 real NOT NULL ,
        pavetemp3 real NOT NULL ,
        pavecond1 char (15) NOT NULL ,
        pavecond2 char (15) NOT NULL ,
        pavechem1 int NULL ,
        pavechem2 int NULL

GO


/****** Object:  Trigger dbo.Web_5627113_3    Script Date: 9/22/98 1:14:05 PM ******/
CREATE TRIGGER Web_5627113_3 ON dbo.thompson FOR DELETE AS
```

```
begin
  exec sp_makewebtask @outputfile='C:\InetPub\wwwroot\tables\thompson.htm',@query='select
datetime, air_temp, rh, dewpt, precip, pavetemp1, pavecond1, avgWspeed=avgwindspeed from
thompson where datetime > dateadd(hour,-12,getdate()) order by datetime desc
',@fixedfont=1,@bold=0,@italic=0,@colheaders=1,@lastupdated=1,@HTMLheader=2,@usern
ame='dbo',@dbname='rwis',@webpagetitle='SQL Server Web Assistant',@resultstitle='Query
Results',@maketask=0,@rowcnt=0
end

GO
```

Appendix D

SQL Server Maintenance

Appendix D: SQL Server Maintenance

A quick guide to SQL programming and maintenance methods are provided in this Appendix.

D.1 SQL Identifiers

- Maximum up to 30 characters
- NOT sensitive to cases
- Allowed characters are letters, digits, #, $, _
- Spaces are not allowed except in form 'Air temp' but Air_temp is a better way

D. 2 Table Creation, Inserts, Deletes and Updates

D.2.1 How to create tables

Let's call the table to be created as 'thompson' which will have the following entries.

datetime	air_temp	RH
11/20/98 10:05	30	50
11/20/98 10:15	35	36
11/20/98 10:25	40	68

Since the values in the column datetime from the above table are unique in every row, use the datetime as the **primary key** of this table. Assuming that database named 'rwis' was created before, the following SQL code will create the table 'thompson'

```
use rwis
go
create table thompson
    (datetime datetime NOT NULL primary key clustered,
     air_temp   real,
     rh tinyint)
go
```

'go' is used to execute multiple SQL instructions in the script file.

D.2.2 How to insert data to the created table 'thompson'

Use the following code.

```
Insert into thompson
          Values ('11/29/98 10:00', 30.5, 40)
```

Note: datetime is alway enclosed by a pair of single quotation.
By the above code, datetime='11/29/98 10:00', air_temp=30.5 and rh=40 are inserted into the table. Again, 'go' instruction can be used in the script file in order to execute multiple SQL instructions.

D.2.3 How to delete a row from a table

Use the following example for maintenance.

```
delete from thompson
     where datetime = '11/29/98 10:00'
```

D.2.4 How to delete a range of rows from a table

```
delete from thompson
     where datetime between '11/29/98' and '12/15/98'
```

Note: '11/29/98' is equal to '11/29/98 00:00'

D.2.5 How to change (modify/update) the existing table cells

```
update thompson
set rh=60 where datetime='11/29/98 10:00'
```

D.3 Data Retrieval

D.3.1 How to retrieve a range of data

```
Select datetime, air_temp, rh from thompson
     Where datetime between '1/1/1998 10:00' and '2/1/1998
     11:00'

Select datetime, air_temp, rh from thompson
     Where datetime < '1/1/1998 10:00'

Select datetime, air_temp, rh from thompson
     Where datetime > '9/1/1998 10:00'

Select datetime, air_temp, rh from thompson
     Where datetime = '9/1/1998 10:00'
```

D.3.2 Retrieve the last 24 hours of data

```
Select datetime, air_temp, rh from thompson
     Where datetime > dateadd (hour, -24,getdate())
          Order by datetime desc
```

'Order by datetime desc' retrieves the latest data first, since the 'desc' key word sorts the largest value first. You can also use 'order by 1' to sort the data by the first column (1 indicates the first column) in an ascending (default) order.

D.3.3 Retrieve the most recently inserted data

Method 1: use a variable by declaring

```
declare @last_time datetime
select @last_time=max(datetime) from thompson
select * from thompson where datetime=@last_time
```

Method 2: a single command approach

```
select datetime, air_temp, rh from thompson
   where datetime=(select max(datetime) from thompson)
```

D.3.4 How to check the time of oldest data entry

```
select min(datetime) from thompson
```

D.3.5 Find the average pavement temprature between '2/1/98' and '3/2/98'

```
select 'avg pavetemp'=avg(pavetemp1) from thompson
where datetime between '2/1/98' and '3/2'98'
```

The `avg()` can be replaced with other functions such as `max()`, `min()`, `sum()`, `count()`.

D.4 Database Maintenance Instructions

D.4.1 Database check instructions

In order to check a database, use the following codes using the SQL query tool.

`dbcc memusage` Provides detailed reports on memory use. It reports: 1) how the server's memory was allocated at startup time. 2) how much memory is used by the 20 largest objects in the buffer cache. 3) how much memory is used by the 12 largest objects in the procedure cache.

`dbcc checkdb` Checks the specified database to see that index and data pages are correctly linked.

`dbcc newalloc(rwis)`
Checks the specified database to make sure that all pages are correctly allocated and used. Details all table information.

`dbcc checkcatalog(rwis)`
Checks for consistency in and between system tables.

`sp_helpdevice` Reports information about SQL Server database devices and dump devices.

`sp_helpdb rwis` Reports information about the specified database.

`sp_spaceused` Displays the number of rows, the disk space reserved, and the disk space used by a table in a database, or displaces the disk space reserved and used by an entire database.

D.5 Backing up

D.5.1 How to Create a Dump Device Using Enterprise Manager

(1) From the Server Manager window, select a server.

(2) From the tool menu, choose Backup/Restore.

(3) Choose Edit and follow the direction.

Example: Device name rwisdump

Device path E:\sqldump\rwisdump.dat

The same can be done by [rightclick –> Edit] from Dump Devices

Dump devices can be also created using the query tool. The following has the same effect as the above.

```
sp_addumpdevice 'disk', 'rwisdump','E:\sqldump\rwisdump.dat'
```

Note: The directory 'E:\sqldump\' must be manually created if it does not exist.

D.5.2 Backup using Dump

The Backup/Restore tool is recommended when a scheduled backup is performed. If it is an immediate backup, the query tool is simple. The following code works well.

```
dump database rwis to rwisdump
dump transaction rwis to rwisdump with noinit
```

For the Zip drive

```
sp_addumpdevice 'disk', 'masterdump', 'F:\masterdump.dat'

dump database master to masterdump
```

or

```
sp_addumpdevice 'disk', 'rwisdump', 'F:\rwisdump.dat'
dump database rwis to rwisdump
```

D.5.3 Backing up or transferring data using bcp from the NT command line

The bcp commands must be run at the NT command line.

D.5.3.1 If the bcp is used for backup, use the native format. It will copy back exactly the same way using binary format. The key option character used is '/n' for this command.

```
bcp rwis..thompson out c:\sqlbcp\thompson_nat /n
```

When a password is asked, supply the password.

The file can be copied back by

```
bcp rwis..thompson in e:\sqlbcp\thompson_nat /n
```

One more useful **bcp** command options:

/F *firstrow*

/L *lastrow*

```
Row # 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 19 17
                    |<------------------------------>|      /F  8     ; 8 to 17
          |<------------------>|                              /L  10    ; 1 to 10
```

Note: When copying data from a file into a table that has no indexes, be sure that the "Select Into/Bulk Copy" has been set to true. Use sp_dboption to set the option:

`Sp_dboption` Displays a list of the database options when no parameter is given.

```
Sp_dboption rwis, 'select into', true
```

SQL server understands any unique string that is part of the option name.

D.5.4 Use the Character format when it is going to be used as input data for other applications or for long term storage.

D.5.4.1 The following example uses a character format with the comma as a field terminator and the new line character (**\n**) as a row terminator.

```
bcp rwis..thompson out e:\sqlbcp\thompson_ch /c /t , /r \n
```

D.5.4.2 If you do not specify the **/n** or **/c** options, the **bcp** utility prompts you for more information. Using this method, you can create a format file along with the output file.

```
bcp rwis..thompson out e:\sqpbcp\thompson.txt
```

```
Enter the file storage type of field datetime [datetime]: char
Enter prefix length of field datetime [0]:
Enter length of field datetime [6]:
Enter field terminator [none]: ,
```

Repeat entering '**char**', and **comma** as the terminator. For the last field, use '**char**' and '**\n**'.

```
Enter the file storage type of field chemfact3 [integer]: char
Enter prefix length of field chemfact3 [0]:
Enter length of field chemfact3 [4]:
Enter field terminator [none]: \n

Do you want to save this format information in a file? [Y/N] y
Host filename: [bcp_fmt] thompson.fmt
```

D.5.4.3 Once the format file is constructed, it can be used over and over again. No need to go

through the above procedure. Use the following command.

```
bcp rwis..thompson out e:\sqpbcp\thompson.txt /f
e:\sqlbcp\thompson.fmt
```

D.5.4.4 Copying the data file back into SQL

If the file was stored by:

```
bcp rwis..thompson out e:\sqlbcp\thompson_ch /c /t , /r \n
```

then, it can be restored back by:

```
bcp rwis..thompson in e:\sqlbcp\thompson_ch /c /t , /r \n
```

If a format file exists due to 2.2, use the format file as:

```
bcp rwis..thompson in e:\sqpbcp\thompson.txt /f
e:\sqlbcp\thompson.fmt
```

D.6 How to shrink the size of the tempdb

The database must be started as a single user. The following describes how to load the SQL server as a single user:

1. From the **service** of NT control window, set the **SQL** and **SQL exec** to manual start.
2. From the NT command line, type in

   Sqlservr /c /m

3. Right click on **tempdb** and choose **Edit**. Choose **shrink** and follow the direction.

Once it is loaded as a single user, the following query can be used to shrink the **tempdb**.

```
use tempdb
go
dbcc shrinkdb(tempdb)
go
```

. Displays the present size and information on how much it can be shrunken

```
dbcc shrinkdb(tempdb, 6144)
go
```

The representation of **6144**: this number must be specified by units of 2k pages, i.e. 6144*2K=12 Mbytes, (6144/512)=12 Mbytes. Let's say, you wish to shrink 80Mbytes, then 80*512=40960 (2k pages) must be in the parenthesis. If you feel it is too complicated, just right click on the tempdb and choose edit and follow the direction.

When a database is expanded by the edit tool (right click –> edit), the meaning of the number should not be confused. It is easy to make a mistake.

Data Device [Master] Size in MB [30]

The number **30** indicates **the amount that you are adding** to the selected database. It is **not** the total amount of your hard disk allocated to the database.

D.6 Database backup and distribution strategy.

The following database management strategy was developed for realtime database applications and may not be suitable for those databases that do not require realtime constraints. In this strategy, two databases are always maintained on-line.

D.6.1 Short-term Realtime Database

This database holds data from present to 2 to 6 month old data. At the end of every month data is moved to the long-term standby database. The role of this database is providing a short term storage for the realtime data, such as realtime web pages and voice services which require frequent and fast access of data. In a relational database, as the number of rows is reduced as is the search time. Therefore, keeping a smaller size database in memory increases the service time and efficiency. Since old data are not frequently used, those should be moved to the long-term standby database. In order to achieve this role, the following SQL scripts are needed.

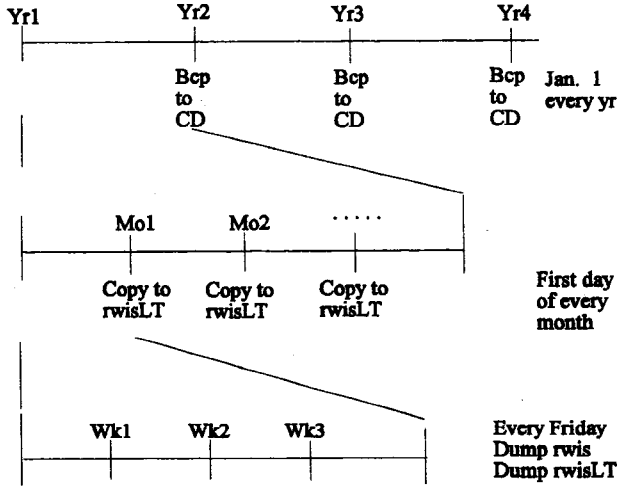
i. A script for monthly data retrieval and copy of data to a standby database. It is executed at the end of every month.
ii. A script for deleting the rows of old data.
iii. A weekly scheduled backup.

D.6.2. Long-term Standby Database

A standby long-term database is a long term database that is used for suppling data for applications which require a large chunk of data, but do not require frequent queries. For example, monthly graphing is only needed to be performed once a month. This database collects data from the short-term realtime database and will keep data up to maximum two years. Every year this data will be archived using an ASCII readable format as a permanent record such as CD-R.

D.6.3. Permanent Retired Database

The permanent retired database is an off-line database which is stored in CD-Rs or Zip disks. It serves as a Mn/DOT archive for the weather history. The data format should be universally accessible ASCII format with the meaning of data supplied right in the same disk. This will allow other applications to read the data without special decoding procedures. A yearly data is saved from the long-term standby database. The backup for this database is done through the bcp command of NT.



A recommended backup plan is summarized using a diagram below.

Appendix E

Voice Server Programming

Appendix E: Voice Server Programming

As a starting point, the CallSuite Wizard can be used to create a main template, from which codes can be added or modified. The examples given in this Appendix provide some development helps as to how to write the code.

For all of the play routines the same general form is used. This is how the "Hello" Play Routine looks like.

```
Public Sub Play_Hello(Vbocx1 As Vbocx)
        If Vbocx1.NrDigits = 0 Then
        Call Vbock1.Play("C:\windows\desktop\SrProj\VOX\Hello.vox", VOXTYPE 24K, "")
        End If
End Sub
```

The first line is the definition of the routine and its parameter. Vbock1 is the default name assigned to a VoiceBocx control by Visual Basic. The second line "if statement" checks to see if there is a digit in the digit buffer. When the application is running in the real system, after a touch tone is pressed, the current routine will quit playing and then next routine will start without knowing an option has been selected. The if statement makes sure the next routine will not start if there is a digit in the digit buffer. If there is no digit in the digit buffer, then it will do the next line which actually plays the file. The first parameter to the command is the path to the sound file. The next is the type of sound file because there is no way to tell if it is not defined. And the last is the digits defined as stop tones. In this case there are no stop tones because it is the welcome message and I wanted to give the file update program some time to update the file before it was accessed. In almost every other play routine, the stop tones are defined as "1234567890*#ABCD". This means that the pushing of any touch-tone key will result in the stopping of the routine. The last line is just the end of the if.

The other types of routines used are the phrase routines. Here is the code for the "Air Temp"

Phrase Routine.

```
Public Sub Phrase_Air_Temp(Vbock As Vbock, Num 1 As Long, Strl As Sing, Num2 As Long)
        Dim Phrase As String
        Phrase = ""
        Phrase = Phrase + "C:\windows\desktop\SrProj\Air_Temp.vox,0;"
        Phrase = Phrase + "num=" = Str(Num1) + ";"
        Phrase = Phrase + "str=" +Str1 + ";"
        Phrase = Phrase +  "num=" +Str(Num2) + ";"
        Phrase = Phrase + "C:\windows\desktop\SrProj\Degrees.vox,0;"
        If Vbock1.NrDigits = 0 Then
        Call Vbck1.PlayPhrase(Phrase, "1234567890*#ABCD")
        End If
End Sub
```

The first line again defines the routine and its parameters. This time there are more parameters to deal with. The first is the usual VBocx1. The next is Num1 which will be passed to the routine as the integer value of the temperature. Then is the Str1 which will be passed as a ".", and last is Num2 which is the decimal number. Now the next two lines of code declares Phrase to an empty string. Each line afterward adds an element to the string until the if statement which works the same as mentioned before. The next line takes the entire string and plays it through in the order the elements were added on. For example when Num1 = 12, Str1 = ., and Num2=6 the final Phrase will sound like this, "The air temperature was twelve point six degrees Fahrenheit." All the Phrase routines are in the same basic form. These routines are in the CallSuite_Routines Module. Another small but very important module is the FileMod Module. The whole module is shown as follows,

```
Option Explicit
Type LocationInfo
        Location        As String * 20
        DateNow         As String * 10
        TimeNow         As String * 6
```

```
    AirTemp         As String * 6
    Precip          As String * 6
    WindSpeed       As String * 6
    PaveTemp        As String * 6
End Type
```

This module is the definition of a variable type LocationInfo. This way we could get the necessary information from the data fields just by stating which information from the location we wanted to get. For example if there was a variable gLocation that was declared as a variable of type LocationInfo, INFO=gLocation.AirTemp would set INFO to be the AirTemp for that location.

The last main part of the code is the actual main program. This is where everything ties together, in the actual main project form. Here is some of the code for the form.

```
    Call Trace("OffHook")
```

Trace is a built in feature of VoiceBocx that simply writes text to the text window in the form of the project. In this case it would put OffHook in the window and the time of the call.

```
gRecordLen = Len(gLocation)
gFileNum = FreeFile
Open "C:\windows\desktop\srproj\data.dat" For Random As gFileNum Len + gRecordLen
```

The first line sets gRecordLen to be the length of the variable field that was specified in FileMod module. The next line sets gFileNum to be the number of the first available file that is not presently open. And the last line opens the file if it exists and creates it if it doesn't exist as the length of one gLocation field.

```
MainMenu:
Call Trace("Running Main Menu.")
```

```
Digit$ = Menu Main Menu(Vbocx 1)
Call Trace("Main Menu returns " & Digit$ & "")
Select Case Digit$
        Case "1"
                Call Menu 1
        Case "2"
                Call Menu 2
        Case "3"
                Call Menu 3
        Case "4"
                Call Menu 4
        Case "5"
                Call Menu 5
        Case "6"
                Call Menu 6
        Case "*"
                Call Menu Star
                GoTo Hangup
        Case Else
                Call Menu Error
                GoTo Hangup
End Select
```

This is the subroutine labeled menu. It starts of by getting the return digit of the users response to the menu and puts it in the variable Digit$. Then the case statements check to see if the return value was 1, 2, 3, 4, 5, 6, or *. Then calls the appropriate routine for each response. If Digit$ is a star or is illegal it will run the proper routine then jump to the hang up subroutine.

```
Private Sub Menu 1( )
        Call Trace("Playback Menu Response 1.")
        Get #gFileNum, 1, gLocation
        Call Trace("Weather at SilverCliff")
        Call Play_SilverCl(Vbocx1)
End Sub
```

This is one of the Menu routines; this one in specifically is for the pressing of the number one. All this does is Trace a couple of things, set gLocation to be first field of length of gLocation in the open file, and it plays "At Silver Cliff." After the main menu is run, it plays the information of the selected location defined in the menu routines. In this case Menu 1 sets gLocation to be the first field, in other words information for Silver Cliff. Then it plays date and time, air temperature, pavement temperature, wind speed, and whether or not there is precipitation in that order.

```
Call Trace("Playing air Temperature")
If (IsNumeric(Trim(gLocation,AirTemp))) Then
        Call Split Num(Val(Trim(gLocation.AirTemp)),Air1,Air2)
        Call Phrase_Air_Temp(Vbocx1,Air1, ".", Air2)
        Else
        Call Play_Invalid_Air(Vbocx1)
End If
```

This is the portion that plays the air temperature. After the Trace it checks to make sure if the air temperature data is a valid number. If it is not, it play the invalid air temperature sound file. If it is valid data, it takes the floating point number and breaks it into the integer value and the decimal value. If the air temperature was -25.9, Air1 would become -25, and Air2 would become 9. Then it calls for the phrase to be played as explained earlier. The other information that follows, like pavement temperature etc., is played in a similar manner.

```
Private sub Split_Num(Num As Double, DigNum As Long, DecNum As Long)
Dim Neg As Integer
Neg = 0
If (Num < 0) Then
        Neg = 1
        Num = 0-Num
End If
DigNum = Format (Num, "000")
DecNum = (Num - DigNum) * 10
```

```
If (DecNum < 0) Then
        DecNum = DecNum + 10
        DigNum = DigNum - 1
End If
If Neg Then
        DigNum = 0 - DigNum
End If
If Neg Then
        DigNum = 0 - DigNum
End If
End Sub
```

This is the Split_Num routine that was used to break up the temperatures. First of all we need to know if it is negative or hot. If it is negative, make it positive by subtracting it from zero and remember that it's negative by setting Neg = 1. The reason for making it positive is it is easier to split it up if it is positive and just make the integer negative when splitting is done. Then DigNum is set to be Num rounded to the nearest integer. Now, take the difference between this number and the original number, multiplied it by ten, and set DecNum equal to that. If DecNum is negative, this means that Dignum was rounded up. If it was rounded up, you need to subtract one from DigNum and add ten to DecNum to compensate. And lastly if the number was originally negative, make DigNum negative again by 0 - DigNum.
Here is the split shown step by step.

Num	DigNum	DecNum
-24.8		
24.8	25	-2
	24	8
	-24	8

These are just some of the codes used in developing the voice server and provided here for a quick guidance for telephony programming. A good reference for learning telephony

programming can be found from the book by Bob Edgar, " PC Telephony: The Complete Guide to Desinging Building and Programming Systems Using Dialogic and Related Hardware," 4th edition [6].

Appendix F

Next-Generation R/WIS Questionnaire

Appendix F: Next-Generation R/WIS Questionnaire

Web Page

1. How easy is navigating throughout the R/WIS site?

2. Is the site map easy to read? Is there anything that could be changed about the site map?

3. Where would you intend to use the live video stream in conjunction with the R/WIS information?

Automated Voice R/WIS Answering System

1. Were you satisfied with the voice and dialog of the voice-information system? If not, what would you like to see improved.

2. Did you feel the system was easy to use?

3. Is the present information adequate? If not, what would you like to add or remove?

4. Would it be better to include menus for each location to hear only the desired information?

Any Suggestions or Application Ideas?