

FINAL
CONTRACT REPORT

**IMPROVED DECISION MAKING
IN CONSTRUCTION
USING VIRTUAL SITE VISITS**

THOMAS MILLS
Principal Investigator

YVAN BELIVEAU
Co-Investigator

KYU JUNG, MARK ILICH,
CHRIS GRAZIANI, KETAN JOSHI
Research Assistants

Department of Building Construction
Virginia Polytechnic Institute and State University



Standard Title Page - Report on Federally Funded Project

1. Report No. FHWA/VTRC 03-CR8	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle Improved Decision Making in Construction Using Virtual Site Visits		5. Report Date February 2003	
		6. Performing Organization Code	
7. Author(s) Thomas Mills, Yvan Beliveau, Kyu Jung, Mark Ilich, Chris Graziani, and Ketan Joshi		8. Performing Organization Report No. VTRC 03-CR8	
9. Performing Organization and Address Virginia Transportation Research Council 530 Edgemont Road Charlottesville, VA 22903		10. Work Unit No. (TRAVIS)	
		11. Contract or Grant No. 98-0239-08	
12. Sponsoring Agencies' Name and Address Virginia Department of Transportation FHWA 1401 E. Broad Street P.O. Box 10249 Richmond, VA 23219 Richmond, VA 23240		13. Type of Report and Period Covered Final Contract Report	
		14. Sponsoring Agency Code	
15. Supplementary Notes			
<p>16. Abstract</p> <p>This study explored the dynamics of information exchange involving field issues relating to construction and the assistance that a virtual site visit can provide to the field decision-making process. Such a process can be used for inspection and surveillance situations in addition to field decision making.</p> <p>The virtual site visit integrates advanced digital audio/video/data conferencing technology in wired and wireless Internet formats to assist in communicating field situations to remote off-site personnel. At its highest development, project information can be transmitted wirelessly through the Internet from a remote construction site to a residency and then to multiple locations through existing communication networks. This research demonstrates the ability to provide high levels of information transfer at relatively low cost, thus enabling critical and timely decisions. This is done through the use of available hardware and software assembled in a manner that allows interactive real-time audio/video transmission and reception.</p> <p>The research identifies the types and applicability of information critical to design and construction operations and the applicability of the Internet and advanced technologies to improve communication and decision making. In addition, the technical limitations on implementation of low-cost real-time audio-visual information transfer were explored.</p>			
17 Key Words Construction management, project-specific web sites, site cams, wearable PCs		18. Distribution Statement No restrictions. This document is available to the public through NTIS, Springfield, VA 22161.	
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 22	22. Price

FINAL CONTRACT REPORT
IMPROVED DECISION MAKING IN CONSTRUCTION
USING VIRTUAL SITE VISITS

Thomas Mills
Principal Investigator

Yvan Beliveau
Co-Investigator

Kyu Jung, Mark Ilich, Chris Graziani, and Ketan Joshi
Research Assistants

Department of Building Construction
Virginia Polytechnic Institute and State University

Project Managers

William H. Bushman, P.E., Virginia Transportation Research Council
Jose P. Gomez, Ph.D., P.E., Virginia Transportation Research Council

Contract Research Sponsored by
Virginia Transportation Research Council

Virginia Transportation Research Council
(A Cooperative Organization Sponsored by the
Virginia Department of Transportation and
the University of Virginia)

Charlottesville, Virginia

February 2003
VTRC 03-CR8

NOTICE

The project that is the subject of this report was done under contract for the Virginia Department of Transportation, Virginia Transportation Research Council. The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Virginia Department of Transportation, the Commonwealth Transportation Board, or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

Each contract report is peer reviewed and accepted for publication by Research Council staff with expertise in related technical areas. Final editing and proofreading of the report are performed by the contractor.

Copyright 2002 by the Commonwealth of Virginia.

ABSTRACT

This study explored the dynamics of information exchange involving field issues relating to construction and the assistance that a virtual site visit can provide to the field decision-making process. Such a process can be used for inspection and surveillance situations in addition to field decision making.

The virtual site visit integrates advanced digital audio/video/data conferencing technology in wired and wireless Internet formats to assist in communicating field situations to remote off-site personnel. At its highest development, project information can be transmitted wirelessly through the Internet from a remote construction site to a residency and then to multiple locations through existing communication networks. This research demonstrates the ability to provide high levels of information transfer at relatively low cost, thus enabling critical and timely decisions. This is done through the use of available hardware and software assembled in a manner that allows interactive real-time audio/video transmission and reception.

The research identifies the types and applicability of information critical to design and construction operations and the applicability of the Internet and advanced technologies to improve communication and decision making. In addition, the technical limitations on implementation of low-cost real-time audio-visual information transfer were explored.

FINAL CONTRACT REPORT
IMPROVED DECISION MAKING IN CONSTRUCTION
USING VIRTUAL SITE VISITS

Thomas Mills
Principal Investigator

Yvan Beliveau
Co-Investigator

Kyu Jung, Mark Ilich, Chris Graziani, and Ketan Joshi
Research Assistants

Department of Building Construction
Virginia Polytechnic Institute and State University

INTRODUCTION

Construction is a process that requires interactive decision-making by the parties responsible for the construction. This often calls for approvals and inspections by off-site personnel, including the owner, architect/engineer, contractor, construction manager, and other personnel from agencies that have decision making responsibility. This creates a need for timely decision making during construction frequently necessitates immediate and simultaneous access to the site and site data by architects, engineers, contractors, and owners. When these parties are in locations other than the project site, problems and the potential for delay becomes acute.

In most situations, the process of locating the responsible personnel and informing them about the situation reduces productivity and creates unnecessary project delays. Additionally, if travel to a remote site is required, additional delays can occur, impacting other projects being handled by involved personnel. Recognizing the importance of the personnel's time and their simultaneous involvement in multiple projects, a full-time site presence by all the parties is impractical. Yet it is essential that timely decisions be made; a loss of time eventually translates into financial loss. Timely information transfer is as necessary to construction as are personnel, materials, and equipment.

Thus the challenge becomes how to deliver critical communications in a timely and comprehensible method to allow decisions to be made by remote personnel. Additionally, effective supervision at the site level and efficient communication at the office level encourage optimum productivity from the personnel involved. In order to ensure smooth operations throughout the construction project, it is essential to have open, accurate, and up-to-date information provided to all project participants (Kerzner, 1995). Informed project communications enables timely decision-making, thus improving project productivity. A breakdown of communications that results in delay can also lead to a dispute, an event requiring more time and money from all parties involved.

PURPOSE AND SCOPE

The goal of this research was to provide an effective solution to the problem of critical and timely decision making by developing communication models that would enable a “virtual site visit” by personnel from the Virginia Department of Transportation (VDOT). The concept of a virtual site visit is to allow personnel to view, evaluate, clarify, or modify what is occurring on the construction site by making the site, project personnel and project data available in real or near real time at multiple remote locations.

The objectives of this research were as follows:

- Identify the types of information exchanges used in field decision making by VDOT field personnel.
- Develop a workable model for using advanced audio/video technology to inspect, report, and problem solve remote projects through the concept of virtual site visits.
- Explore and document the limitations to establishing and implementing the technical network, both as it presently exists internal to VDOT field operations and in terms of the technical limitations of current technology, including the real-time capabilities and system resolution required to facilitate decision making.

Therefore, to achieve the research objectives, the investigators explored two interrelated areas: (1) the field communications activities that engage the project participants and the techniques that are used to complete and record the decisions reached, and (2) advanced communications technologies, including Internet capabilities. Completed investigations into these areas should lead to an information process map of field communications needs and advanced communication techniques for implementing a virtual visit.

LITERATURE REVIEW

Field Project Communications

During the construction phase of a project it is essential that good and timely communications prevail throughout the process. The ever-changing dynamics of construction require that all parties be kept apprised of issues that can ultimately affect the cost, schedule, or performance of the work. In addition, the very nature of construction creates its own problems because of the remoteness of the project from the project participants.

The common fast track project delivery method demands collaboration and the sharing of timely and accurate information between the field and remote offices. Therefore, access to real-time information is critical to the overall construction process as it translates to effective decision making, ultimately leading to a successful project. The implications of improving information flow during the construction process force industry leaders to reevaluate coordination and communication strategies (Chinowsky, 1998).

One of the largest construction projects to use integrated information exchange is the Boston's Central Artery/Tunnel project otherwise known as the "Big Dig." This is an \$11 billion project with over 100 contractors and 36 field offices working around-the-clock shifts. At its start in 1986, very little thought was given to software automation and document management. There was a multitude of different software packages being used to enter data. Daily progress reports, pay quantities, and deficiency reports were all being entered in different software products, few of which freely exchanged data. Data gridlock occurred because of the time lags in reporting and integrating the figures; both contractors and field offices began issuing reports that conflicted with internal data being collected by field project managers.

In 1992, Bechtel, the project management coordinator, decided that the information control was out of hand and implemented an Oracle7 database to create a Construction Information System (CIS) using Structured Query Logic (SQL) to generate standard reports. This system has available online in real time the reports from over 12,000 field engineers. Requests for Information (RFI) inquiries were immediately available for response by the appropriate project personnel. As of 1998, the Big Dig project manager consultants had integrated a web-based project-specific web site (PSWS) as a document management system with contract management software, estimating software, and scheduling software included (Harrison, 1998).

Building an Integrated Project Information System

As early as 1984, various participants in the construction process began to understand the potential for using computer technology of capturing (selecting, gathering, and storing) construction project information into a single database. Although this group of owners, designers, constructors, and academicians were more concerned with design and life-cycle databases, they did recognize that technology enhancements would move faster than the organizations implementing new computer information systems. Additionally, this group was fully aware that project owners must demand the use of integrated project databases or implementation would be even slower (National Academy of Sciences, 1985). The categorization of information established by earlier researchers has contributed to an understanding of how databases can be organized to contribute to improved workflow processes. Vanegas brings much of the previous work on categorization of information management and advanced communications technology together for strengthening the interface between design and construction workflow processes (Vanegas, 1994).

In the late 1980s and early 1990s the term *information superhighway* preceded the Internet and was widely used to reference the emerging concept of electronically delivered information. Although there are cultural, legal, and organizational barriers to using this information, the technical barriers must first be removed. Cleveland recognizes that in construction these technical barriers fall between automated information delivery to the job site and use of that information by the construction team. In the delivery of information, each participant and/or software vendor custom designs the information in a form that restrains its use by others on the project team. With regard to automated information use, Cleveland is also critical of requiring all members of the team to use the same software. His insight leads to a vision of technology that would enable dissimilar computer applications to integrate and deliver data in various formats that can be used by the different team members (Cleveland, 1994).

This vision led to Cleveland and Bentley Systems taking the lead on the development of a design/construction Internet-usable software language standard called XML (extensible markup language) and aecXML (architecture/engineering/construction/XML). It is believed by many that the proliferation of this collaborative enabling technology will work to reduce the fragmentation so common in construction. Thus, in the next five years the design/construction industry will depart significantly from the current construction production paradigm of paper-based field documents (Inglesby, 2000). The future of construction project management points toward the use of advanced computer technology for computer-integrated construction (CIC) and team-based web-enabled project management.

Massachusetts and Ohio have implemented a total life cycle document management system for design and construction information on the life histories of their states' bridges. Massachusetts compiled a multimedia catalog using Integrated Bridge Inspection Information System (IBIIS) to acquire, transfer, and archive their states' stock of bridges. The documentation includes drawings, ratings data, digital photographs, and full motion video clips in an integrated single click-and-point, searchable database. Ohio implemented a \$1.8 million customized bridge-management system to computerize digital data on its over 40,000 bridges. The information can be updated by the user and contains data similar to those in Massachusetts's system (Leung, 1996).

Construction Communication Mapping

Much of the work on computer-integrated construction (CIC) has focused on product models representing data about components. Fisher, Froese, and Pham (1994) recognize this and propose to expand the concept of CIC to be the electronic sharing of project information among project participants. To break down the barriers to implementing true CIC, information must be shared laterally as it is created or the structure will remain fragmented and underused, as the user usually sits at the bottom of project organizations. This is aptly stated by the comment that "usually a team responsible for a specific task has no control over the information flowing into its task, and control but no interest in the information flowing out of its task." Fisher et al. also note that information is not considered a value-added component of a project, i.e., it does not put work into place. Thus information is considered overhead and should be expensed or accounted for in the project as such.

Essential to using advanced computing technology for field decision making is an understanding of the job site informational needs. Research on using wireless communications for construction information needs has been undertaken and reported by the Construction Industry Institute (CII). A valuable component of the CII report is the categorization of field informational needs into nine categories linked to four formats for communicating information. The report also analyzed each of these information categories in terms of its appropriateness to be supported by wireless communication. The CII study concludes that the only wireless technology currently available to transmit video communications for construction purposes is wireless local area network (LAN) (de la Garza, 1996).

Internet Information Exchange in the Design and Construction Industry

The Internet revolution is without a question the single most exciting development in communication in the Information Age. In 1998 there were over 36 million host computers connected to the Internet in over 140 countries (Nielsen Media Research/CommerceNet, 1998). As of March 2000, Nua Ltd., the major Internet survey agency, estimates over 304 million users worldwide of which 134 million (approximately 45% of the U.S. population) live in the United States (Nua Ltd., 2000). If past growth is any indication of future growth, world Internet users should double in the next 2 years.

Now, more than ever, instant access and sharing of information are easy through the “ready-made” networks provided by the Internet. This influence has redefined the way business is approached. For instance, the development of electronic mail enables peoples at remote locations to send and receive written, voice and data messages in a matter of seconds. Other tools such as web browsers permit users to navigate the Internet through the use of hypertext and hypermedia links to access a plethora of resources in the form of texts, graphics, audio, and video. Thus Internet e-mail now rivals faxing as a common communication medium for construction project participants.

These Internet tools, along with others, help the business community to communicate, coordinate, and collaborate more efficiently. A direct outgrowth in construction of the Internet as a communication tool is the development of PSWS. These sites in fact are project extranets devoted exclusively to construction management and allow participants to visit project site data on a 24/7 basis. The essence of the Internet for construction is that project data are online and accessible instantaneously by any of the project participants through any Internet portal.

Project-Specific Web Site

With the advent of the Internet and the web, other mechanisms of integrating project data with sounds and images have become prevalent. E-mail and Internet information access have changed significantly the way work is developed and approached. Within the last year, the concept of project extranets has taken the construction industry by storm. A PSWS is a private web site that distributes various types of project data on demand to the various project team members. Information available online at the PSWS or virtual project site are CAD files, specifications, digital photographs, meeting reports, shop drawings, correspondence, schedules, pay quantities, and an almost endless list of project documents. Some PSWS also provide collaborative redlining through online conferencing and site observation through web-based site cameras (Novitski, 1999). By accessing a project extranet or PSWS for online construction management, a team member is in effect performing a virtual site visit. Year 2000 was considered the year of early adopters for online PSWS, 2001 for near mass acceptance, and 2002 for Europe and Asia (Williams, 2000).

Notable among these dot com software applications for PSWS are MP Interactive Corporation (<http://e-builder.net>), Bidcom (<http://web.bidcom.com/>), Meridian Project Systems (<http://web.projecttalk.com>), Bentley Systems (<http://projectwise.bentley.com/>), and Autodesk (<http://buzzsaw.com>), the creator of AutoCad. Each of these vendors has created software that allows a project team to set up a PSWS and use this location for the virtual project site. This

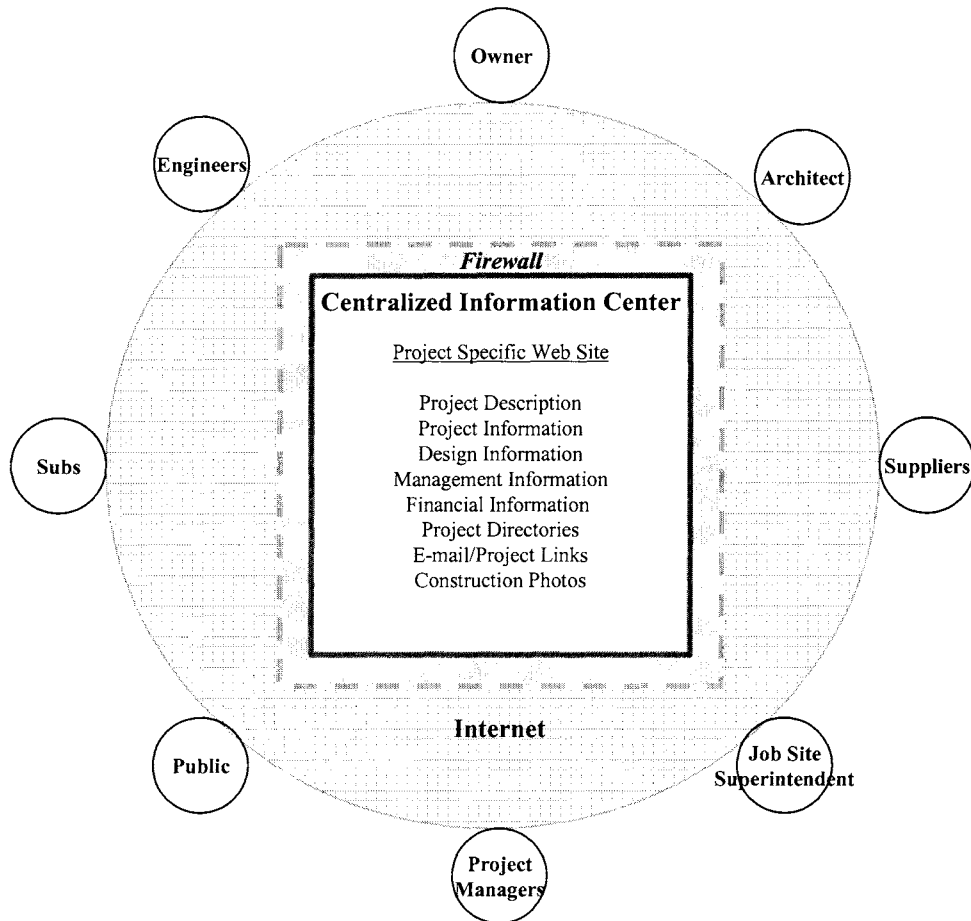


Figure 1. Project-Specific Web Site (PSWS) Diagram

software is available for client use by either purchase or renting. A third method of acquisition is to create a PSWS internally. Figure 1 is a component diagram of a PSWS.

The simplicity and convenience of the Internet have become catalysts in converting what is now a paper-dominated industry into a digital communication mode, particularly through web-based project collaboration and management (Phair, 1998).

Advanced Communications Technology in Construction

Liu and colleagues conducted pioneering work in using multimedia technology for as-built project information, particularly by superintendents in compiling daily diary entries. In his work, Liu et al. (1995) recognizes that the daily job diary is a comprehensive project document that provides baseline progress data and is useful in case of claims and disputes. By including multimedia content in the daily diary, a more complete picture of actual project progress is available than through the written word. Liu extended this work to incorporating a wireless “digital hardhat” for field data collection. This concept incorporates a pen-based computer and a hardhat-mounted camera for capturing on-site images in a multimedia format. This capture is then wirelessly transmitted to a site server for web access. Liu states that prototypes are in testing, but his

publication lacks the technical data on the hardware and software utilized to implement the “digital hardhat” (Liu, 1997).

Other work coupled with the concept of gathering multi media field data is Coble’s work in capturing digital stills and transferring wirelessly back to a wired server connected to the Internet (Coble et al., 1998). The advent of digital cameras with wired transfer capabilities has made digital imaging a common project data-gathering tool, although it is not automated on a wireless basis. Beliveau, Cody, and Mills have also proposed wireless wearable computing linked to the web as an alternative to actual field site visits, their concept of virtual site visits. Systems identification and technical data for bandwidth needs and wireless transmission modes linked to a project communications matrix and a field trial indicate this medium can be used successfully (Beliveau et al., 1998; Mills and Beliveau, 1998).

METHODS AND MATERIALS

The research approach for this project focused on creating a working model of field communications and the acquisition, transfer, and archiving (ATA) of needed information for decision making using advanced communications technology. These two major areas of investigation, field project communications, and advanced communication technology, were researched in an effort to provide an effective solution to critical and timely decision making by developing a virtual site visits communication model.

The task activities followed a very simple progression. The first task was to select a project to assess current construction processes used by VDOT. This was done by designating the Wilson Creek Bridge construction near Blacksburg, Virginia, as the specific project vehicle for setting up the research. The structure, the tallest in Virginia, is a cast-in-place, segmental arch, reinforced concrete structure over 1,500 feet long. The second task involved meetings with VDOT personnel, construction management inspectors, design engineers, and contractors to determine the status of internal project communications. This work was used, as the basis for developing a roadmap for advanced communication modes and a strategy for creating a “virtual project site” that could be accessible regardless of time and location. With subsequent foundation work in the mechanisms of VDOT field communications, research was conducted in both wired and wireless computer networking capabilities.

Project-Specific Web Site

To facilitate the concept of a virtual site visit, a web-enabled database component (see Figure 2) of PSWS was created. The site was installed on a web server as the base site for engaging in virtual site visits. In creating this prototype, the application of inputting daily or weekly reports to a virtual construction website was developed and deployed. Active server pages (ASP) are used to create the Internet application that allows a site user, an inspector possibly, to input his or her project daily reports into the MS *Access 97* database.

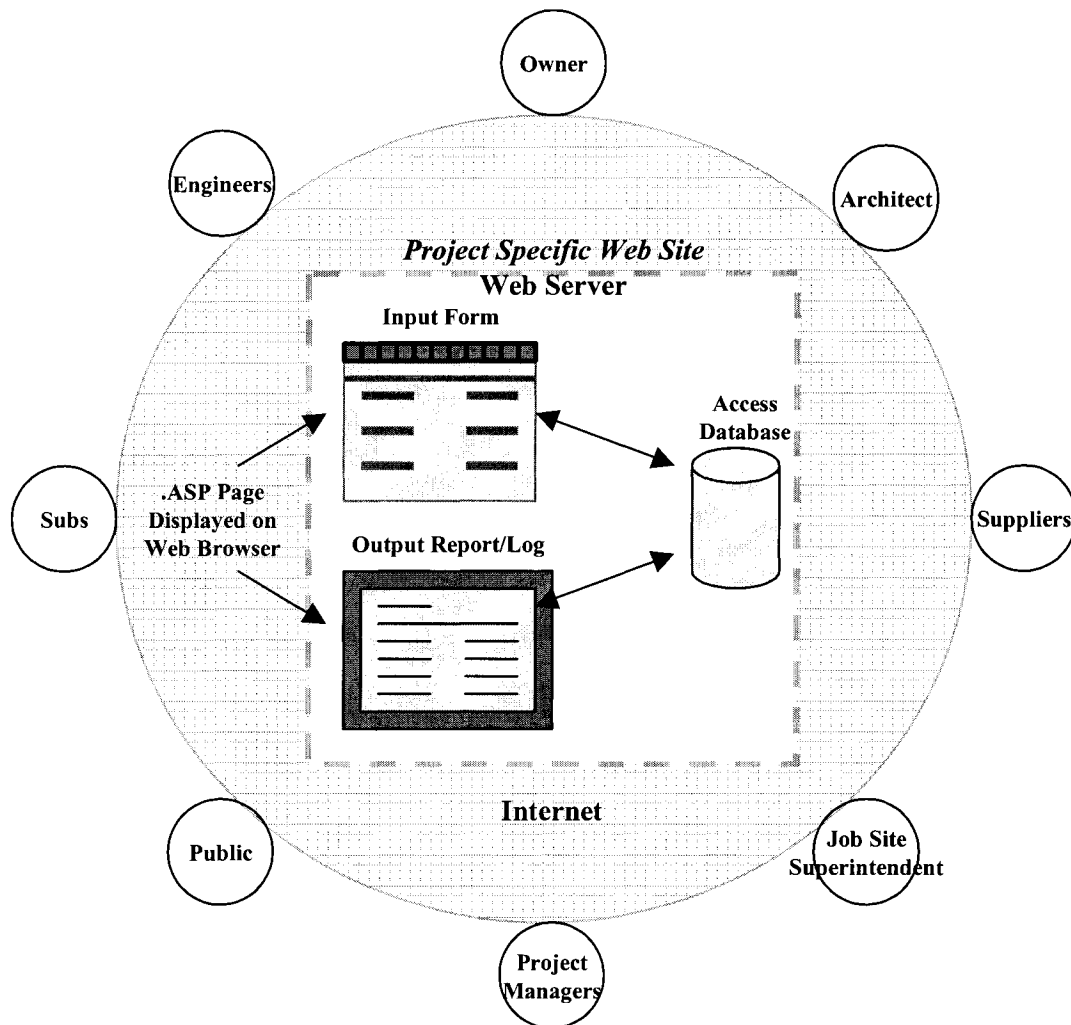


Figure 2. Web-enabled Database Diagram

ASP is a programming environment that provides the ability to combine HTML, or Hypertext Markup Language, scripting, and components to create a powerful Internet applications that runs on the server. HTML is the current coding language used to create Hypertext documents for use on the web. Two components were used to create the prototype web-enabled database:

1. A computer with an MS Internet Information Server that functions as a web server and as the central information center that host the MS Access Database.
2. Creating a mechanism that allows the remote project participant to control the database through the Internet. This is achieved by using Drumbeat 2000 to create Active Server Pages that deployed the database-input form. The ASP in the server converts the database-input form as HTML dynamic documents. In addition, an ODBC (Object DataBase Connector) was utilized to provide a connection between the database and the ASP page.

Advanced Communications Technology

Simultaneously with the creation of a PSWS, investigation and procurement of hardware and software were undertaken to implement the virtual visit. Among the hardware and software investigated were digital cameras and e-mail, statically based interactive site-mounted cameras, high-speed network access, portable and wearable wireless LAN computing devices, voice activated software, and portable desktop videoconferencing. Wireless cell phone service was only briefly reviewed for applicability and not explored in depth.

Figure 3 details the operational structure for implementing automated image capture of predefined construction activities. This ease of implementation of sitecam in the construction industry has attracted a number of construction companies. The hardware requirements of the model diagramed in Figure 3 are as follows:

- *Web camera server:* This camera acts as its own web server, provided the camera is assigned a static Internet protocol (IP) address.
- *Internet connection:* A project that can tolerate visual project updates at frequencies greater than 1-minute intervals will find a dedicated 56K-modem connection adequate. For near real-time pan, tilt, and zoom user-controlled cameras, a minimum 128K Integrated Services Digital Network (ISDN) connection is required.
- *Project or company web server:* Create a link or file transfer protocol (FTP) image to the web server. Also, program the server to capture and store project photos at specific time intervals with time and date stamp for identification purposes.

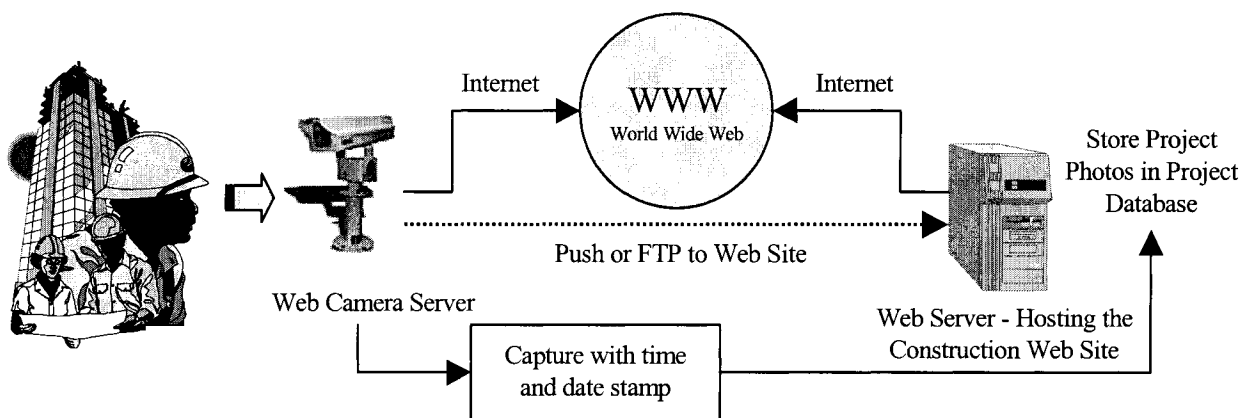


Figure 3. Construction Sitecam Model

Wearable Wireless Virtual Visit

The meshing of these investigations yielded a wireless, portable virtual visit prototype for the ATA of needed information. Several experiments were conducted using the derived communication matrix and multi media aspects of a virtual site visit.

The belt worn, Windows 95 computer (WPC) shown in Figure 4 is configured with two PC card slots and a head mount display (HMD) unit. It is equipped with external ports for color monitor, keyboard, mouse, parallel, serial, and external drive connections. Voice and video capture is accomplished using a miniature camera and microphone attached to an audio-video (AV) capture card. This card fills one of the PC card slots to enable the usage of a videoconferencing software package providing full-duplex sound and video capabilities. This allows for full duplex, or two-way, video/audio conferencing on the WPC. A wireless LAN adapter card fills the other PC card slot. This enables the mobile user to have a connection to the Internet, enabling videoconferencing capabilities in the field (via *MS NetMeeting*). For keyboard and mouse capabilities, a hardware device called Twiddler is used. Twiddler has computer-input capabilities and is designed to act as a mouse and a keyboard. It allows the mobile user the mobility and convenience to input information while freeing up the other hand. The WPC is also equipped with voice-activated web browsing software.

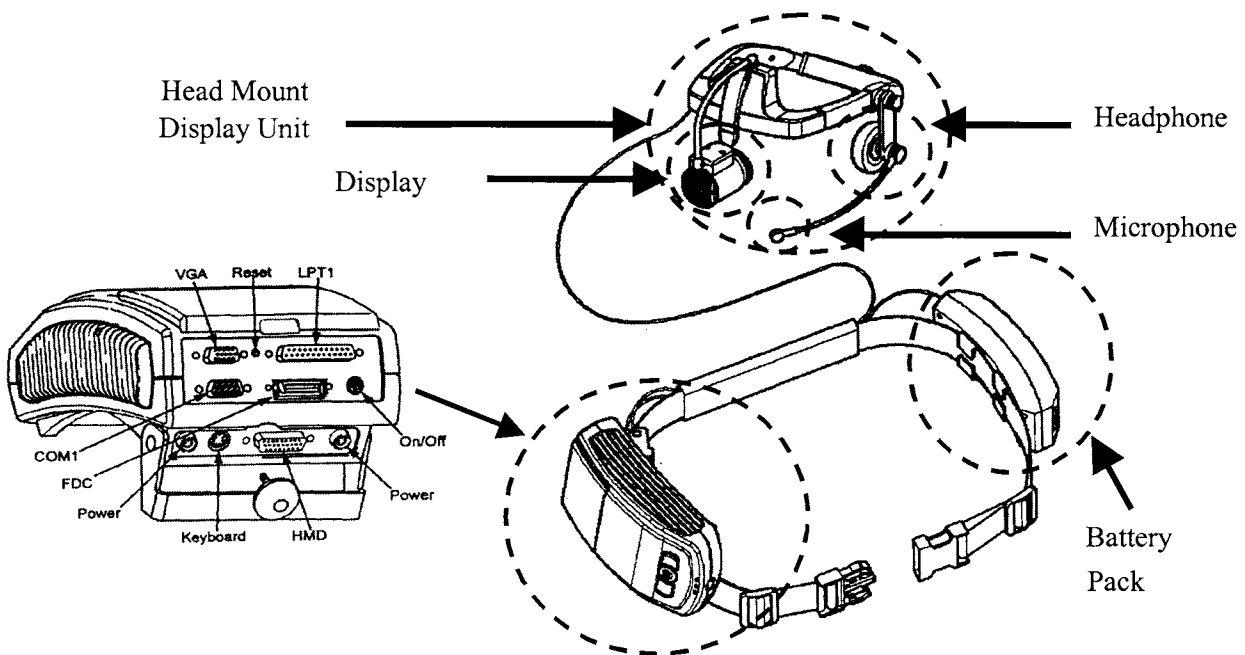


Figure 4. Complete Belt Worn Personal Computer (WPC) with Head Mounted Display (HMD), Xybernaut Corp.

To effectively implement a virtual visit at a remote workforce, a wireless local area network (WLAN) is required. This was accomplished using a WaveAccess Jaguar AP132™ Access Point with a dual 6-in whip antenna and a wireless PC card adapter with an internal antenna. WaveAccess has subsequently been purchased by Lucent Technologies and is manufactured under the Lucent name. The Jaguar is a 2.4 GHz WLAN that operates in unlicensed bands using digital frequency hopping spread spectrum (FHSS) radio technology. It is easily designed to create its own network with data rates between 1.6 Mbps and 3.2 Mbps and can be connected to any Ethernet network. The radio technology used, the antenna selected, and the environment in which it operates all limit the range. Although geographically limited, this system communicates using line of sight communications. The tested virtual visit configuration is shown in Figure 5.

In the configuration shown, there are three main areas of focus: Mobile Field Unit, Jobsite Trailer, and Off-site Computer Server Unit. The Mobile Field Unit describes the components of the WPC that an individual wears out into the field. The Jobsite Trailer is where the WLAN receiver resides. This transceiver access point AP 132 as shown in Figure 5 is hardwired to the Internet via an Ethernet connection. The Off-site Computer Unit is any computer connected to the Internet. The model shown could have an architect, engineer, or inspector on the other end communicating with the Mobile Field Unit.

The appropriate communication matrix for a hypothetical site inspection or construction conflict requiring a virtual visit videoconference at the workforce is shown in Figure 6. Elements of Figure 6 are derived from the generic construction communications matrix shown in Figure 7.

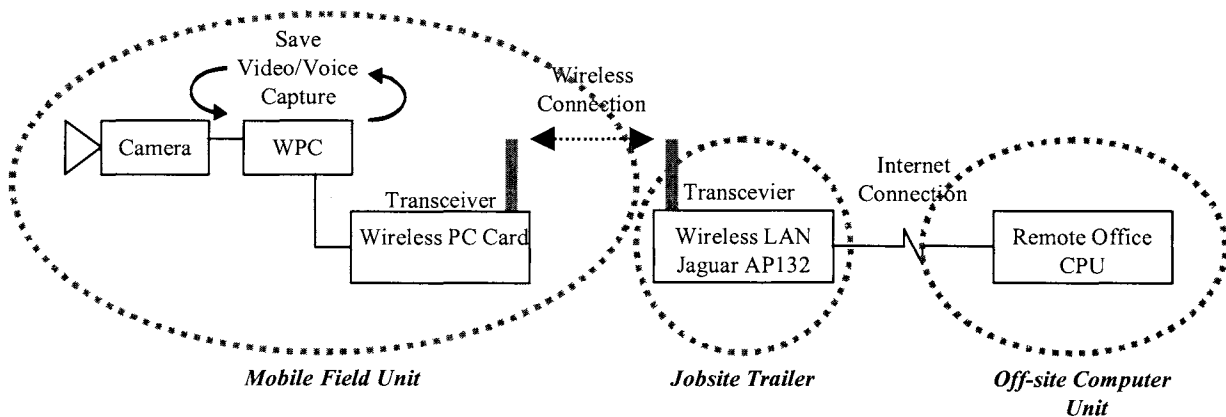


Figure 5. Virtual Visit Configuration

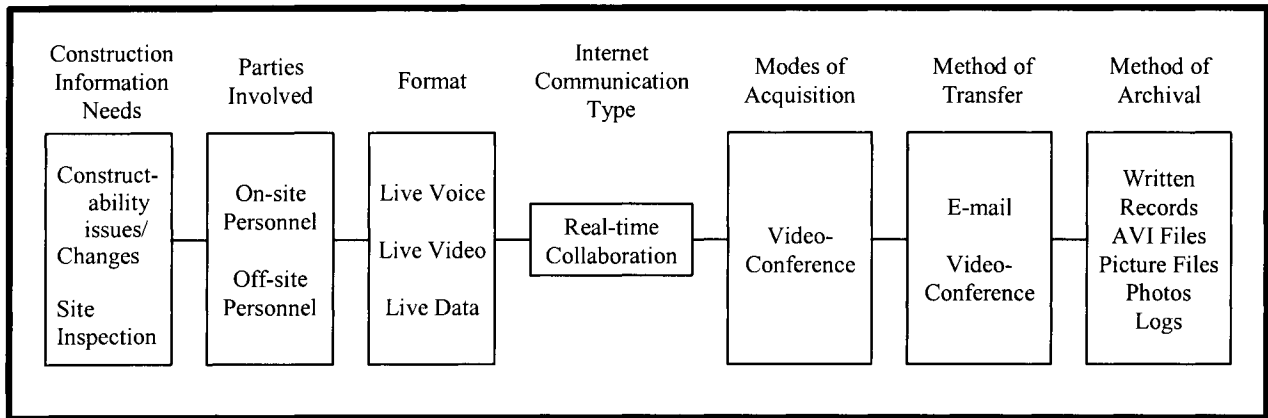


Figure 6. Virtual Visit Videoconference Communication Matrix

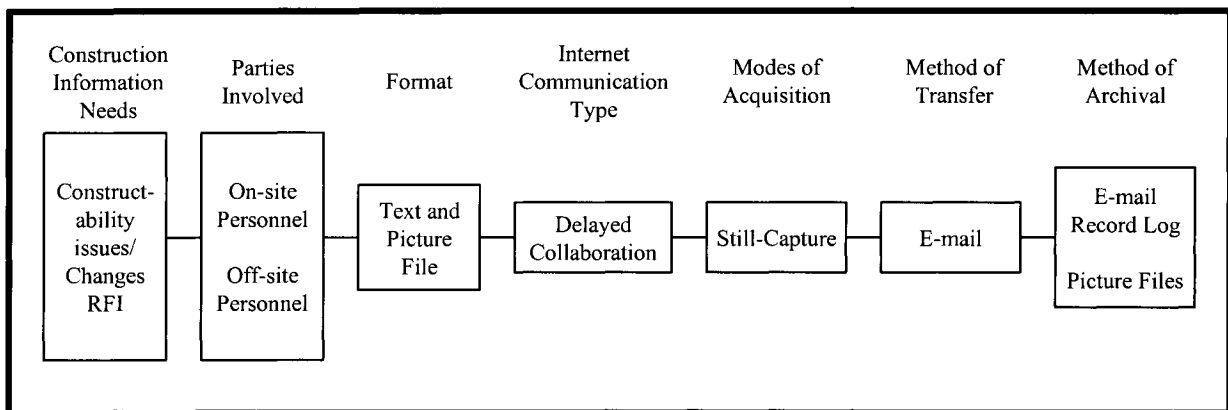


Figure 7. Modified Communication Matrix for E-mailing Digital Images

RESULTS AND DISCUSSION

Field Project Communications

In meeting with the Wilson Creek Bridge project personnel, it was quickly apparent that there was little effort to integrate and make project documentation digitally accessible. At the beginning of the project, the construction management inspectors possessed only internal corporate e-mail capabilities and no Internet or web capability. By the close of this research, each of the consultant inspectors had Internet accessible e-mail and web browsing capability. The on-site lack of rudimentary Internet capabilities altered the initial strategic approaches to the research.

Voice

The interviews conducted among construction personnel identified the various methods of communication and their usefulness as a value added commodity. The predominant verbal

communication from site to off site was a land line telephone. Limited cellular phones were available. There were two problems with cell phone usage: (1) signal strength is extremely weak at the site, and (2) VDOT's policy was to minimize cell phone usage as a cost control measure. Internally, construction field personnel relied on two-way radio for field communications.

Written

Overall internal written documentation is organized for immediate user accessibility but with the exception of "official reports" is fragmented with regard to standards and lacks any accessibility through a single unified database. The organizational strategy for project information appeared dependent on the construction manager consultant, who on this project was McDonough, Boylard, Peck.

A limited analysis of project documentation is as follows:

- *Payment request:* These are compiled and submitted monthly and are maintained through a VDOT developed electronic "Construction Workbook." Data to input pay quantities are transferred from the project dairies, which are in turn compilations of inspector's reports.
- *Project diaries:* This is an electronically compiled record for reporting equipment, labor, and daily work activities. These diaries reside on individual personal desktop computers in Microsoft Access and were accessible only through those particular workstations. These diaries are considered by some site personnel to be "the only binding source document for work activities." The ability to use virtual site visits and integrated project databases as vehicles for claims and disputes is not the focus of this research and has not been pursued.
- *Engineering reports:* Although electronically prepared these are maintained on site as bound hardcopy.
- *Inspection reports:* Field inspections are conducted on a daily basis and maintained in both electronic and hard copy. The dairy is used extensively to compile and maintain these field reports. Test reports, including density, and concrete tests would be classified within these reports.
- *Schedules:* Schedules are electronically prepared and maintained on-site in separate data files. *Suretrack* by Primavera Systems is low-cost powerful project management software though used exclusively on this project for critical path method (CPM) scheduling. As-planned and as-built project schedules are monitored by VDOT consultant inspectors.
- *Submittals/shop drawings:* Although many of these shop drawings are electronically prepared, they are reviewed and maintained as hard copies at the following locations, VDOT/Richmond: VDOT/Christiansburg, the job site, and the contractor's office. Shop

drawings being reviewed or revised are maintained at either the engineer's office or the supplier's location and are not accessible by other project participants.

- *CAD drawings*: Not all projects will use CAD documents, although the Wilson Creek Bridge project does. It is uncertain as to the level of electronic access of these drawings by any but the engineers of record.
- *Plan revisions*: Multiple manual copies exist at various locations.
- *Specifications*: These exist, as do the drawings, in digital format but are exclusively maintained, accessed, and searched on-site in a hard copy format.

What is quickly obvious from the documentation review is that electronically prepared documents are still predominantly maintained and accessed using paper-based organizational structures. Additional work was done on categorizing the types of construction communication and their documentation and value added characteristics. This work was later used in developing a strategy for conducting virtual visit experiments and mapping appropriate communication technology for specific purposes.

Construction Communication Matrix

Because of the complex nature of construction, it is difficult to identify all instances of whom, why, and when information is integrated by being gathered, stored, and shared. The communication matrix shown in Table 1 is a useful tool to illustrate and map the different scenarios involved in information exchange during the construction process.

The communication matrix was created as a tool for organizing an approach to mapping appropriate technology with communication characteristics and the subsequent decisions. In order to map a strategy for comparison of Internet communication tools and their benefits, the matrix should be modified specifically for the construction situation and critical need (See Figures 6 and 7). In making a decision the three elements of information are essential, information must be acquired and transferred, and once acted upon the decision must be archived. This matrix is structured to guide in choosing a technology consistent with all aspects of the matrix. For example, a simple telephone conversation may be a justifiable method to resolve one situation, whereas in another situation, a site visit from an outside party may be required.

Therefore, the objective is to determine the optimum situation for the communication mechanism to be used. As an example, a communication matrix was developed for various project situations in an effort to analyze and measure the differences between the different communication mechanisms used to meet a specific information need. Figures 6 and 7 modify the matrix by identifying the parameters that involve the decision to communicate via routine e-mailed digital photos (Figure 7) or real-time inspections (Figure 6). An analysis of this matrix configuration will reveal the strengths and weakness of this communication technology with this information process.

Table 1. Generic Construction Communication Matrix

Construction Information Needs	Parties Involved	Format	Internet Communication Type	Methods of Acquisition	Modes of Transfer	Method Archive
Request for Information						
Materials Management	Owner		Static	Mail	Mail	Written Record
Cost Management	Architect	Voice	Management and Coordination of Information	Telephone	Telephone	Video Tape
Schedule	Engineer	Video		Fax	Fax	Audio Tape
Job Site Records	Contractor	File Data	Interactive Internet Collaboration	E-mail	E-mail	Computer File
Submittals	Subs			Digital	Video-Conference	
Means & Methods	Suppliers				Logs	
Safety					Written	
Equipment Management						
Quality Assurance						

One of the surprising results of establishing the matrix concept was the development of a typology for categorizing Internet communication relative to construction needs. The resulting typology for categorizing Internet communication for the architect, engineer, and contracting (A/E/C) industry is broken down into three ascending levels of information complexity. These are identified in Table 1 and elaborated upon here.

Static Information

Static Information (SI) is a one-way communication tool that provides communication in the form of text, graphics, and video. An example of SI that the research project has tested is sitecam technology (see Figure 3). Through any standard web browser, using a sitecam, the status of a project can be monitored from anywhere in the world at any time of the day. Recent advances in hardware and software configurations have made sitecam technology practical and cost efficient for use in the A/E/C industry. Project members can automatically acquire, collect, and distribute project photos and video clips throughout the life of a project. Sitecam does not have decision-making or collaborative communication capability with other users.

Coordination and Management of Information (CMI)

The second type of Internet communication tools is categorized as the Coordination and Management of Information (CMI). These communication tools function to coordinate and manage

project information in the Internet. They normally involve the processes of capturing, sharing, and archiving information. An example of an Internet communication model that coordinates and manages construction project information is a web-enabled database using ASPs.

Interactive Internet Collaboration

Interactive Internet Collaboration (IIC) involves the participation of remote project members in team problem solving. This virtual site visit involves the integration of wireless communication, computer networks, and video conferencing to enhance decision making by providing live video and audio to off-site personnel.

Using IIC, members can interact to resolve field situations or complete inspections that might normally delay or hinder the progress of a project. This virtual site visit inspection model is shown in Figure 8.

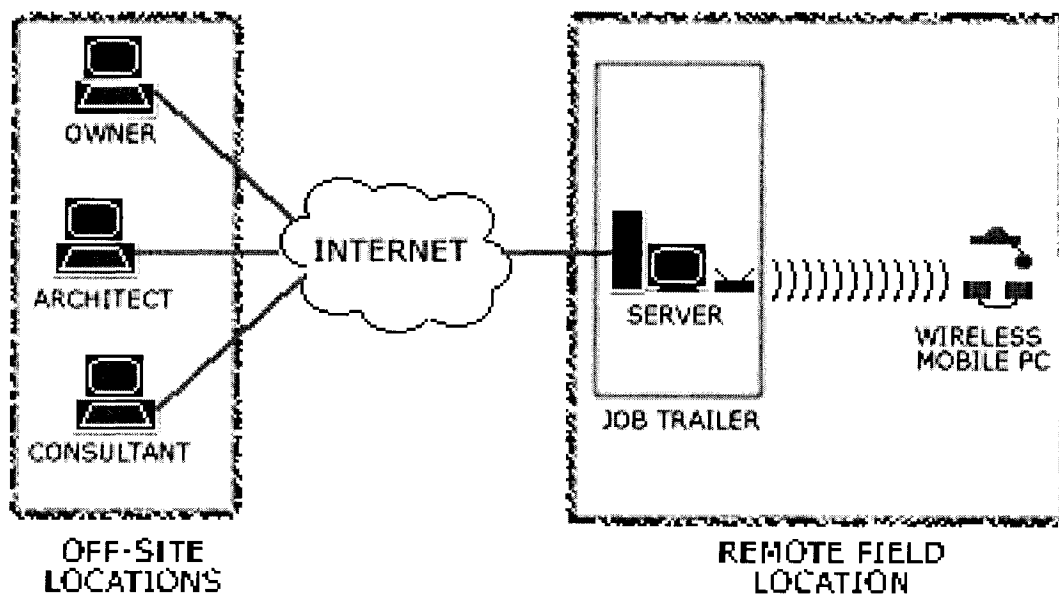


Figure 8. Collaborative Virtual Site Visit Inspection Model

Web-enabled Database

A transferable web-enabled database, within a PSWS, using Microsoft *Access* was created and programmed into the VA Tech/VDOT Virtual Visit Site web server. This web-enabled database was created to establish a server-side remote online presence for instant access to necessary project documentation. All the previously identified documentation could be placed on the server and become searchable and immediately accessible by all necessary project personnel. The web-enabled database was created with password security that allowed qualified user access.

The only active modules created and tested were for remote surveillance site cameras, job photos, and weekly reports. These modules were setup to allow remote users to access, and with the proper security clearance upload and download data to the virtual site. This database can reside alone on a desktop as an integrated database, but without some form of networking it requires site visitation to access. By being web-enabled, the database can reside on a remote web server (see Figure 2) and thus when accessed be transformed into the user's workstation, resulting in a more user-friendly approach than the standard file transfer protocol (FTP) used by many.

The PSWS server for this research was located on the Virginia Tech campus, although it could reside anywhere Internet access is available. In order for the wireless components of a virtual site visit model to support the functionality of wireless communications, an on-site Internet server is necessary as is high-speed Internet access. Although the researchers were lead to believe that a high speed Internet access could be inexpensively provided to the remote Wilson Creek Bridge site it was not feasible until the second quarter of 2000, just as the grant expired. The necessity of high-speed bandwidth is important to a successful demonstration of real-time field communications between remote sites. Because of the inability to deliver high-speed Internet access to the project site, the Virginia Tech campus was used for test purposes.

Project-Specific Web Site

Prior to creating a PSWS, an investigation into commercial availability was conducted. Many of the better products were available only as services. Additionally, there are limitations to the interoperability of these sites with other vendors' products. The lack of a universal standard and a potential for sole-source purchasing pushed the research into the direction of building a universal PSWS.

Because much of the existing on-site project database originated as Microsoft *Access*, a web-enabled product utilizing Microsoft *Access* was considered important. Other databases could be utilized for similar purposes. All commercial products reviewed had deficiencies. This led to the development of a virtual visit research-based web site that could be transferred to any or all VDOT construction projects and used as the foundation for creating virtual site visits. Contained within the web site are areas for access to job site photos, current weather conditions, reports, project documentation, and site camera observation. Additionally, modules can be created for project diary, pay request, shop drawings, progress monitoring, correspondence, and schedules. Each of these modules can be searchable and contain current and updated information available for simultaneously review by multiple participants.

Advanced Communication Technology

Sitecam Technology

The sitecam technology was tested using both static and user-controllable video cameras. Long term testing has demonstrated that this technique is usable for extensive project monitoring, executive and project team investigations, automatic image retrieval, archiving, and automatic distribution to and from remote locations to individuals at other locations.

Using Sitecam technology the researchers were able to post static project images on the virtual visit web site at predetermined intervals utilizing file transfer protocol or “push technology.” This allows anyone with access to the web site to view current static or live images of the project at any given point in time. Both web-based user-controllable cameras and fixed automatic updating technology were tested and demonstrated as successful technologies for real-time archiving of project images. The sitecam was successfully used to capture, time-stamp, and store project still photos at specific time intervals as well as capture and store QuickTime™ video movies.

Virtual Visit Inspections Using Wearable Computers

The most alluring and difficult technology to use is the body-worn personal computer with an HMD. The experiments involving real-time field inspection activities using free Microsoft *NetMeeting* software were successful in the laboratory, although not foolproof, and were dependent on connectivity conditions of varying quality ranging from high to low. The results are not intended to diminish the success of the experiment but to establish the limits of success so that future researchers can draw from the deficiencies and make improvements.

The reliability of quality imaging is a major drawback to organizational acceptances and its use would depend on the critical nature of the need. What was successfully demonstrated was that an individual remote from the project site could in real-time visually observe, inspect, and direct project site activity for reaching a critical decision. This is an important concept, and as technology improves, the reliability of the quality of conducting a virtual visual inspection will increase.

Because of the miniaturization of the HMD, there were operator difficulties in reading the display. Eyestrain was quick to occur while operators tried to gain familiarity with the 1½-in. ocular viewfinder and its reliance on the wearer’s dominant eye. The user continually squints, closing one eye to peer into the viewfinder. Another limitation that affected the user was the cursor control. The computer comes equipped with a standard tactile joystick key. The difficulty in manipulating the key in the field makes operation difficult at best. The twiddler was substituted and made cursor control and click selection simple and easy. Typing on the twiddler was an ergonomic as well as an intellectual challenge with a single key acting as four to five different character keys. The voice activated *Web-Assist* browsing software worked reasonably well although other voice-activated text software required additional training time to improve its error rate. Combining the technical problems of screen viewing, cursor manipulation, and periodic signal degradation, the users tended to become frustrated quickly and diminish the perceived usability of the system as a tool for inspection and decision making. In addition, MS *NetMeeting* is a point-to-point audio/video conferencing software thus limiting the number of simultaneous participants in the virtual visit to two parties. Therefore, the only technical deficiencies were in the user interface and the limitations of single-point video-conference software.

The WLAN system works exceptionally well within a limited line of sight range of approximately 200 feet. Different antennae and additional access points would theoretically increase the distance and range. The only problem of significance in the WLAN occurred during field roaming when the mobile unit traveled beyond range or left the line of sight.

In summation the wearable system was a workable platform for the required communication exchange between offsite and on-site personnel, and adequate for decision making.

CONCLUSIONS

This research expanded the definition of virtual visits beyond the project site into a unifying principle built around a single multimedia database with dynamic access. The conclusions that are drawn are based on the results of this research applied to the Wilson Creek Bridge project as no other projects were investigated.

It was evident on the Wilson Creek Bridge project that information structures are fragmented and that current leadership in defining the daily organizational structure for field information strategies was led by the construction management consultant. Although there were organizational strategies for daily inspections and pay items, there was no unified database for using digitally prepared information in its native format or for instantaneous access by all project members. Technology is advancing faster than the organizational structures can adjust. What exists is a paper-based culture using digital data.

The beginnings of informational roadmapping were evident from the construction communication matrix and the web-enabled database. This roadmapping is directly transferable to improve the culture and organizational structure for corporate jobsite information management. The literature documents the efficiency, savings in time and money, and quality improvements that result from the unification and integration of field data. Additionally, project specific web sites can provide the nucleus for unification of this information in a single retrievable location.

Advanced communications techniques, notably web-based sitecams and digital image via email, are reaching mainstream usage. Technology permits the practice of wireless, virtual visits for improved decision making regarding highway constructability issues, delay potentials, and project inspections.

Rural project locations if selected for WLAN virtual visits must have a connection to the Internet backbone.

A systematic mapping and unification of information needs, and a reasonable appraisal and implementation of the appropriate communications technologies can accomplish three things:

1. Reduce data replication.
2. Increase accessibility to data for decisions.
3. Improve the quality of information exchange resulting in a faster, cheaper, better-built project.

RECOMMENDATIONS

The following recommendations are directed particularly at the construction and construction maintenance aspects of VDOT operations.

1. *Recognize and implement a digitally fluent organizational culture.* VDOT should take the lead in implementing a procedure for all constructors, designers, inspectors, subcontractors, suppliers, and construction managers to prepare construction data in digital formats. This should involve the total life cycle of projects and project documentation.
2. *Conduct detailed research investigation that maps VDOT's enterprise-wide construction information needs, communication types and acquisitions, and transfer and archive modes of communication.* This should be with the intent of pursuing a strategy that unifies job site data. This investigation should be completed before any system designs and software solutions are procured. A software solutions vendor should not be engaged until the study identifies VDOT's structural needs. Procuring through a solution vendor prior to mapping construction information needs will result in a vendor trying to fit VDOT's needs into their existing software solutions instead of building a solution to meet VDOT's needs.
3. *Conduct before-and-after studies to validate the return on investment in time/cost savings and in quality improvements gained by implementing an integrated jobsite information database.*
4. *Conduct a series of productivity demonstration studies using interactive sitecams and wearable computers in Internet accessible areas.* These studies should be two-fold. Perfect the tools and processes for implementing real-time Internet Interactive Collaboration (IIC) using handheld or wearable computers, and focus on productivity gains resulting from the use of virtual site inspections.
5. *Make several of the advanced communications techniques, notably web-based sitecams and digital image via email, standard field procedures.* If implemented, these activities should be incorporated as overhead items with project value added. Regarding the major concerns of a transportation construction project (constructability, delay potential, or project inspection), the practice of wireless virtual visits for improved decision making should, within limitations, be implemented.

REFERENCES

Beliveau, Y., Cody, D., and Mills, T. Virtual Visit: Telecommunication for the Construction Industry. *Journal of Project and Construction Management, Institution of Construction*, Barton, Australia, Vol. 4, pp. 36-54, 1998.

- Bucknam, M. D., Hawkins, E. F., and Sanfillippo, M. A. *Net Gains*, Civil Engineering, pp. 49-51, November 1998.
- Chinowsky, P. S. *A Benchmark Study of Web Communications*, ASCE Journal Of Computing in Civil Engineering, pp.822-831, June 1998.
- Cleveland, Jr., A.B. *Electronic Information, Delivery & Use at the Jobsite*, Construction Business Review, pp. 50-52, March/April 1994.
- Coble, R., Qu, T., and Sun, W. *Digital Still Image Transfer Via Wireless in Construction*, 1998, Proceedings of the Associated Schools of Construction Region 2 Conference, Atlanta, GA, pp. 1-10, 1997.
- de la Garza, J., and Howitt, I. *Wireless Communication and Computing at the Construction Jobsite*, RR 136-11, Construction Industry Institute, University of Texas at Austin, 1997.
- Fisher, M., Froese, T., and Phan, D., *How Do Integration and Data Models Add Value to a Construction Project?* Proceedings of Fifth Construction Congress, Minneapolis, MN, 1997.
- Harrison, Ann, *Unsnarling Information for the Real Superhighway*, Software Magazine, pp. 82-92, March 1998.
- Inglesby, T., ed. *The Tools are Changing, A Look Beyond Today and Tomorrow*, Constructech, pp. 21-28, Jan/Feb 2000.
- Kerzner, H.. *Project Management: A Systems Approach to Planning, Scheduling, and Controlling*, New York, Van Norstrand Reinhold Inc., 1995.
- Leung, Albert, *Perfecting Bridge Inspecting*, Civil Engineering, pp. 59-61, March 1996.
- Liu, L. Y. *Construction Field Data Collection Using the "Digital Hardhat."* Proceedings of Fifth Construction Congress, Minneapolis, MN, 1997, American Society of Civil Engineers, Reston, VA, pp. 399-404, 1997.
- Liu, L.Y., Stumpf, A. L., Chin, S. Y., Ganeshan, R., and Hicks, D. *Construction Daily Log Management System Using Multimedia Technology*, Computing in Civil Engineering, Proceedings of the Second Congress, pp. 1084-1089, 1995.
- Mills, T., and Beliveau, Y. *Virtual Site Visit Using Wearable Computers*, The 1998 International Conference on Wearable Computing, Fairfax, VA, May 12-13, Xybernaut Corp., 1998.
- National Academy of Sciences Building Research Board, *DATABASES, Integrating the Building Process*, The Construction Specifier, Alexandria, VA, pp. 56-61, January 1985.

Neilsen Media Research/CommerceNet. 1998. CommerceNet/ Neilsen Internet Demographics Study, June 1998, <http://web.commerce.net>

Novitski, B. J. *Three Approaches to Project Extranets*, A/E/C Systems, pp. 22-24, Winter 1999.

N Ltd. Internet Surveys, http://web.nua.ie/surveys/how_many_online/index.html, New York, 6-26-2000.

Phair, M. *Collaborative Systems Move Closer*, Engineering News Record, December 1998. <http://web.enr.com/new/fo713.asp>

Vanegas, J. *Strengthening the Design/Construction Interface Using Electronic Imaging, Document Management and Work Flow Technologies*. Proceedings of Fifth Construction Congress, Washington, DC, American Society of Civil Engineers, Reston, VA, 1997.

Williams, A. *AEC Dot Coms Breed Construction Partnerships*, CADENCE, February 2000.