

ABSTRACT

Lee, Jaeseok. Value Analysis of Wi-Fi Agent Functions In Construction. (Under the direction of Dr. Leonhard E. Bernold).

By nature, construction is an information intensive industry. However, effective communication between process units, such as laborers, equipment, tools, and management is presently hampered as each is an “island of information.” The goal of this research project was to investigate the effectiveness of Wi-Fi agent-mediated communication in construction. In order to test and validate key components of this concept, a prototype Wi-Fi agent network was installed and tested during the construction of a new Chilled Water Plant (hereafter called “Cates”) at NC State University campus.

In a preliminary study, key elements of a multi-media Wi-Fi communication network were tested to learn about functionality and interoperability. With the knowledge gained, six Wi-Fi agent systems were designed and installed. They included: 1) Two 802.11b backbones, 2) weather sensing, 3) weather warning, 4) three video monitoring, 5) interpersonal audio/video, and 6) Web/FTP. All systems functioned in time for tests during the steel erection phase of the Cates Project.

While a questionnaire survey was organized to gain insights into the industry’s state-of-practice, five interdependent Wi-Fi enabled agent functions were selected for experimental testing and value assessment: 1) Crane alert, 2) ubiquitous site inspection, 3) ubiquitous problem solving, 4) ubiquitous sensing and data access, and 5) e-Document

management. The successful field experiment demonstrated that Wi-Fi ubiquitous networks are technically feasible and able to link the “islands of information” selected for this study.

With the data collected during the field study phase, the value of the five Wi-Fi functions was evaluated. Valuable benefits were found to include: 1) lowered crane accident risks by employing the autonomous alert agent function, 2) reduction in cost/time for travel and on-site inspection enabled by the ubiquitous site inspection function, 3) increased worker safety due to 24/7 remote monitoring, 4) decreased work interruptions and RFI processing costs through the ubiquitous problem solving function, 5) automated equipment monitoring, data logging, and documentation with the ubiquitous sensing and data access function, and 6) elimination of cost and time associated with printing and distribution of blue print drawings and specification facilitated by the e-Document management function.

The presented research project validates the functionality of Wi-Fi agent communication in construction. Field study results support the overarching premise that this information technology creates a multitude of opportunities to gain significant value through improved means of communication.

VALUE ANALYSIS OF WI-FI AGENT FUNCTIONS IN CONSTRUCTION

By

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BIOGRAPHY

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1. INTRODUCTION

1.1 Background

Ancient people used various types of communication channels, such as hand gestures and smoke signals to satisfy communication needs beyond the reach of the human voice. Later, early postal systems (i.e., foot, horse, coach) were developed to overcome the range restrictions, however there was still the issue of delivery speed. Eventually, the transport of a message was revolutionized by the telegraph introduced in 1844 in America. Morse codes were quickly replaced by telex, telefax, radio, and early computer communication (Integrated Publishing, 2005). In recent years, with advances in the computer field, ubiquitous computing coupled with new emerging wireless services has demonstrated the potential for overcoming communication problems of the construction industry.

The construction industry is a major sector of the U.S. economy. According to a recent employment situation report from the U.S. Bureau of Labor Statistics (BLS), construction employment in the U.S. in the 2nd quarter of 2005 accounts for roughly 7.2 million, or 5.4 percent of non-farm payroll employment. Moreover, the value of construction put-in-place, a measure of the amount spent on design, engineering, and construction, totaled \$1 trillion in May 2004, according to the Census Bureau. This amount is equivalent to roughly eight percent of the U.S. GDP.

For the past two decades, the construction industry has attempted various efforts to improve its performance, including partnering, just-in-time, lean construction, and packaged delivery systems. However, none of these efforts has resulted in a major improvement of performance (on-time, on-budget, and satisfying quality expectations) (Kashiwagi et al., 2004). Already in 2000, Teicholz reported that the labor productivity of the construction industry stagnated since 1964, in contrast to the manufacturing industry.

1.2 Performance Barriers in Construction

In 2003, Nuntasunti summarized the five factors preventing the construction industry from improving performance: 1) Fragmentation of the construction industry, 2) unique nature of construction projects, 3) temporary nature of relationships, 4) competitive bid approach, and 5) lack of suitable communication network.

The fragmentation is mainly caused by the large number of specialized contractors that are needed throughout the life of a project, requiring multidisciplinary collaboration to work with each other (Cutting-Decelle et al., 2001). As a result, a large amount of information is created by independent, or loosely connected, organizations and individuals involved in a project. The situation is further complicated by the fact that work tasks and organizational units are highly interdependent.

At the construction level, with its highly dynamic nature, resources such as materials, tools, workers, etc. move constantly within a site, from site to site, or from the factory shop to the sites, creating a complex pattern of intertwined flows. This unique

and dynamic characteristic of construction makes the establishment of an effective communication network extremely difficult.

Recently, NIST published an in-depth study about the lack of interoperability between systems and organizations in construction. Gallaher et al. (2004) stated that many parties in different disciplines often work in isolation from each other and are not able to share information efficiently due to incompatible hardware and software. Gallaher estimated the losses due to the incompatibility in the capital facilities industry as \$15.8 billion within the U.S. alone. Other studies from the Construction Industry Institute (CII) have approximated that considerable improvement in the integration of software systems could result in savings of up to 8% of total construction cost, a 14% decrease in project duration and a 5-15% reduction in operation costs.

In March 2005, the FIATECH (Fully Integrated and Automated Technology) Consortium started an “Interoperability Requirements for the Roadmap” project to identify software interoperability requirements for every element of the FIATECH Capital Projects Technology Roadmap. Being the essential first step towards attaining the goal of seamless interoperability across the entire project life cycle, this project is being moved forward in concert with the technical framework of the FIATECH Roadmap Element 9: Lifecycle Data Management and Information Integration.

1.3 A Ubiquitous World for Construction

Ubiquitous computing embeds electronic devices into every day objects that make them “effectively invisible to users, and provides a natural interface to them” through

ubiquitous networks (Wikipedia, 2005). Ubiquitous computing emerged over a decade ago but has only recently gained visibility with the diffusion of wireless networks and mobile applications (Avital and Germonprez, 2003).

In a ubiquitous computing environment, the physical space will be integrated with the cyber world and multi-media IP-enabled computing devices will be given the capability to become a active service point of the Internet and automatically communicate with each other using automated software agents able to gather information from other devices, tasks, and humans and to perform predefined tasks in coordinated manner.

The key components that facilitate this new “world of omnipresent communication” are the All-IP environment and Wi-Fi technologies ranging from simple sensors, chips, and RFID tags to MEMS (Micro Electro Mechanical System) that can be built into equipment and tools such as cranes, dump trucks, forklifts, excavators, saws, etc.(VTT, 2004).

1.3.1 Wi-Fi Technologies

According to Abowd and Essa (1997), ubiquitous computing causes a complete shift in the way stand-alone hardware will interface and communicate with others in a totally autonomous fashion and without cables.

The elimination of cables to communicate between computing devices is critical step toward advanced communication in construction since the dynamic project sites make cables difficult to maintain.

In May 2004, ASCE/CI launched the Wireless Construction Committee to promote the implementation of wireless communication in dynamic construction environments. Regarding this effort, Nuntasunti and Bernold (2003) developed and tested a prototype 802.11b wireless network system called Visual-based Integrated Wireless Site (V-IWS) on a mid-size building construction project. The system was designed to allow every project participant access to real-time project information and to share their data interactively with others permitted to the Web-based site.

Related to the wireless construction, Yka Marjanen (2003), a research scientist at the VTT in Oulu Finland proposed an innovative vision for wireless construction as follows: “In the future the construction equipment, cars, production processes and workmen at heavy/highway construction site can be networked with wireless technology and communicate automatically to tally in real time cubic yards of earth moved and compacted to what density and at what water content, avoid accidents of all types, etc.”

1.3.2 Autonomy with Agent Technologies

As indicated in section 1.2, the construction industry is considered one of the most information intensive industries where communication has to occur between a large number of units within different disciplines and locations throughout construction.

As a result, the interdependence of the process units and the increasing amount of information has reached to a point where only automated communication will sustain its further growth. It is not surprising to observe an increasing interest over the last few years in a technology where software agents cooperatively conduct predefined tasks

without human intervention and are able to respond speedily to changes in the dynamic environment.

According to Knublauch and Rose (2000), the agent technology provides communication mechanisms for autonomous, situated, and pro-active information exchange. In addition, it can control diversified information flows and initiate pro-active information dissemination. They indicate that agent systems relieve humans of routine tasks and repetitive activities by automating information processing.

Integrated with Wi-Fi technologies, agent technology is expected to serve as a key-enabling tool for intelligent construction in the near future (Benmammar and Krief, 2004).

1.4 Problem Statement

Access to accurate and relevant information at the appropriate time and with the required quality is instrumental in managing construction projects effectively. As has been demonstrated, today's *modus operandi* creates numerous obstacles to efficient communication between process units. This section identifies several problem areas in the current practice of information exchange.

1) Poor productivity created by ineffective material flow management: For example, the present method of shipping, unloading, storing, and installing prefabricated building elements for structural steel erection is considered inefficient because information for the elements is not circulated well to relevant people and synchronized in

a timely manner. This causes steel erectors and suppliers to be faced with production waste such as idle crews, trucks waiting to be unloaded, and collateral waste in the field, thus resulting in poor productivity.

2) Low equipment utilization and accidents: The construction sites are geographically distributed and the nature of the construction process requires personnel and its numerous heavy equipment to be continuously moved around jobsites. Because virtually no data is collected about the condition and environment of equipment on and off site, it is impossible to manage those resources with the goal to minimize idle time. In addition, lack of data concerning the “machine health” leads to poor management and inappropriate operation/accident.

3) Ineffective handling of design and as-built documents: Currently, paper prints are used to exchange design, shop, erection, as-built drawing between project participants. Required documents are usually gathered or delivered “manually” so that the time to get updates and revisions to all affected people is often excessive. Duplication of effort and inconsistencies, errors, losses of information, and extensive time needed to find relevant information are common.

4) Poor job performance caused by disconnected production units: Information exchange is hampered by the lack of effective communication among various types of process units. Delays in even communication lead to resource idleness,

costly work rotations, and errors. Furthermore, paper-based handlings of change orders and RFIs have accelerated difficulties in information exchange in a timely manner.

Even though the project participants have used various project management tools to improve their communication, existing approaches only address information flow problems between humans. On the other hand, real time information from other critical resources (e.g., engineered material) is not available.

It has been suggested allowing all process resources to communicate with each other at all times lets them quickly respond to changes in the dynamic environment both on and off site. Such a capability could be instrumental in eliminating many process wastes while offering new opportunities to create new value.

1.5 Research Hypotheses

For the research project, the following four hypotheses are formulated.

While the advent of Wi-Fi technologies may present new dimensions to wireless communications in a dynamically changing work site, issues with respect to reliability, speed, and security remain. In reality, it has been known that overall network performance for 2.4 GHz wireless LANs depends on site environmental situations. Under the presence of RF (Radio Frequency) background noises, the overall performance of a network can be negatively affected (e.g., decreasing retransmission rate).

Furthermore, manmade obstacles such as civil structures in the line of sight between the receiving and transmitting antennas have different effects on attenuation and multi-path fading. Actual transmission rate is dependent on the environmental conditions.

(Hypothesis 1)

On construction sites, manmade obstacles and various types of equipment and machinery can significantly degrade the performance of a wireless network, restricting operating range and data throughput.

Currently, many Requests for Information (RFIs) arise at the jobsite because of unresolved problems. RFIs are sent via fax, e-mail or Federal Express along with hand-drawn sketches, pictures, and even digitally marked-up copies of drawings to the technical expert in the office. The expert would either return the approved answer or call a person at a field site until the problem was solved. But even then, in most cases, it is very difficult to have a clear enough understanding to diagnose a problem and to make recommendations immediately without a site visit. Wireless and Internet mobile technologies have opened the door to finally address problems of remoteness.

(Hypothesis 2)

A multi-media IP-enabled communication can let technical experts in the office provide real time guidance and assistance to field personnel.

The control of the potentially large amount of information creates the danger of data and information overflow. Information agent-based technology may be capable of

serving or processing information by providing the relevant human and/or machine with the right information in real time. In wireless environments, such agents are able to autonomously perform routine tasks or even analyze incoming data to detect potentially dangerous situations in advance. However, almost all of the agent applications have been used to deal with individual problems and support specific information requirements working in a stand-alone manner each with its own and unique information representation, file formats, and terminology. This has been identified as one of the critical obstacles to connecting “islands of information”, leading to incompatible agent systems.

(Hypothesis 3)

An Information Agent-Mediated Communication (IAMC) model provides an efficient platform for M2M (Machine-to-Machine) interaction under wireless construction environments. As a core requirement for agent communication, neutral agent ontology will help in offering interoperability between incompatible agent systems.

(Hypothesis 4)

By connecting today’s “islands of information”, Wi-Fi agent functions offer a diverse set of opportunities to create new value.

1.6 Research Objectives

The overall objective of this study is to develop, test, and evaluate an agent system mounted on Wi-Fi network (hereafter called Wi-Fi agent system), which could play an

important role in providing an omni-communication space to the process units for structural steel construction. Six sub-goals have been defined as follows:

- 1) Evaluate key communication channels and current state-of-practice tools in construction.
- 2) Study and model material and information flow for structural steel construction processes to establish a data need and analysis of critical communication problems.
- 3) Develop a prototype neutral data format for structural steel construction processes.
- 4) Develop and implement Wi-Fi agent system to support real-time and interactive information sharing among process units.
- 5) Collect and analyze performance data to determine the functionality, reliability, and associated effects of Wi-Fi agent system.
- 6) Assess the overall economic effects of Wi-Fi agent system.

1.7 Research Methodology

The scope of this work is limited by its focus on structural steel construction. The research is broken down into eight phases:

Phase 1: Literature Review

Knowledge and concepts related to information in the construction domain will be investigated beyond the field of construction. Telecommunication networks, interoperability issues, information theory, standard, modeling, and logistics concepts will be examined. Furthermore, state-of-the-art information and communication

technologies (ICT) related to development of Wi-Fi agent system will be reviewed to define their practical applications and limitations.

Phase 2: Survey on the State-of-Practice

In order to identify a manager's perception of the current state-of-practice in digital and wireless communications and determine key benefits for and barriers to the use of wireless technologies in the U.S. construction industry, a questionnaire survey will be organized and implemented.

Phase 3: Field and Factory Observations and Material Flow Model

Field and factory observations will be conducted to identify material and information flow in structural steel construction. Structural data analysis will be used to investigate and model the process as well as identify areas for productivity improvement.

Phase 4: Design of Wi-Fi Agent System

The focus of this phase is the development of Wi-Fi agent system for early weather warning and information logistics for structural steel construction. The Wi-Fi agent system includes the following combined set of hardware to build a communication network: 1) Network cameras, 2) solar panels and battery, 3) access point, 4) a router, 5) repeaters, 6) antennas, and 7) sensors.

Phase 5: Installation and Test of Wi-Fi Agent System

The Wi-Fi agent system is deployed at the construction site for the Cates Project, which is located on NC State University's central campus. Its functionality and reliability will be tested indoors and outdoors. Special considerations associated with the equipment installation and start-up will be identified.

Phase 6: Data Collection and Analysis

In this phase, field data will be collected during the steel erection period. Focusing on its functionality, reliability, and feasibility, the overall effects of the Wi-Fi agent system will be evaluated. Requirements for and barriers to agent technologies in wireless construction will be identified.

Phase 7: Value Assessment

In this phase, the values of the field-tested Wi-Fi agent functions will be analyzed utilizing six different value measurement techniques organized according to the five Wi-Fi functions.

Phase 8: Summary, Conclusions, and Recommendations

In this phase, the research will be summarized and conclusions of the research will be derived. In addition, guidelines for future research will be developed.

1.8 Organization of the Dissertation

This dissertation is organized into 11 chapters. Chapter 1 gives an overview of performance and interoperability problems in the construction industry and emphasizes the importance of communication among process units. Research problems and objectives are also presented. In Chapter 2, literature is reviewed to shed some light on theory and state-of-the-art technologies necessary for conducting this research. In Chapter 3, the role of agent communication mechanisms and the issue of semantic integration in the construction domain are discussed. Chapter 4 describes the analysis of the survey results to obtain insight about the state-of-practice of digital and wireless technologies in the construction industry and explore the industry's opportunities and barriers. In Chapter 5, existing structural steel construction processes are observed and their materials and information flows are identified to understand structural steel construction. In Chapter 6, a neutral data format for structural steel erection is designed to guarantee the interoperability between disparate applications. Chapter 7 proposes an agent-mediated communication concept and the framework of Wi-Fi agent network and presents the development of Wi-Fi agent network and system. Chapter 8 describes the installation of Wi-Fi agent system at the Cates Plant on University's central campus. Additionally, FCC and University's wireless policies are reviewed. The focus of Chapter 9 assesses the functionality of Wi-Fi Agent system followed by an analysis of collected field data. Chapter 10 presents an evaluation of Wi-Fi agent system using both quantitative and qualitative methods. Finally, Chapter 11 concludes the thesis with a

summary, conclusions, and recommendations for future study. The appendices hold detailed information about some of the issues discussed in this dissertation.

2. LITERATURE REVIEW

The purpose of a literature review is to assess and summarize the information that is relevant to the objectives described in section 1.6. Nine topics are covered in this chapter.

2.1 The Concepts of Information

According to Webster's Dictionary, information is defined as a "communication or reception of knowledge or intelligence obtained from investigation, study, or instruction". On the other hand, communication is determined as "a process by which information is exchanged between individuals through a common system of symbols, signs, or behaviors".

Project Management Body of Knowledge (PMBOK) published by Project Management Institute (2004) states that communication entails the exchange of information and includes the broad concepts of deciding when they call for it, in what form it be delivered to them, and who requests what information. PMBOK shows that the sender is responsible for making the information clear, so that the receiver can take it correctly. The receiver is also accountable for confirming that the information is understood correctly. According to PMBOK, communication has manifold dimensions: 1) Formal and informal, 2) written and oral, 3) internal and external, 4) listening and speaking, and 5) vertical and horizontal.

Attia (2002) classified communication from a slightly different angle. He described the difference between synchronous and asynchronous communication, providing examples for both types in Table 2.1. When all communicating parties have to be present at the same time, communication is defined as synchronous communication. On the other hand, communication is called asynchronous when participants send and receive messages at different times.

Table 2.1 Classifications of Communication Methods (Attia, 2002)

Synchronous	Asynchronous
<ul style="list-style-type: none"> • Face to face meetings • Phone (regular, wireless) • Video-conferencing • Computer Chat (text) • White board (drawing board) • Computer mediated video-conferencing 	<ul style="list-style-type: none"> • E-mail, E-mail attachments • Voice mail • Mail (regular, express, hand delivered) • Collaboration software • Fax • On-line message board

Information Measurement Theory (IMT) was developed by Kashiwagi (2002) to evaluate the use level of information associated with related factors. The left hand side of Figure 2.1 demonstrates that a type A owner employs more information and changes faster than a Type C owner does. The two-way charts on the right hand side of the same Figure show the comparative amounts of factors. For instance, a Type A owner uses a high level of performance information, makes very few decisions about construction conflict, minimizes quality control, and has very high performance. On the other hand, the Type C owner uses more specifications and makes more decisions, leading to the very low level of performance.

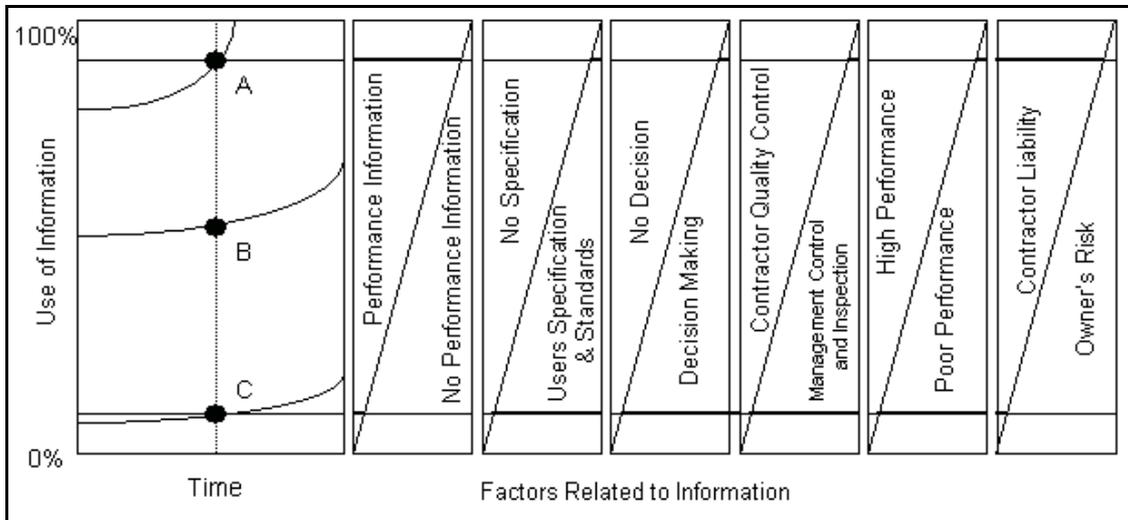


Figure 2.1 Level of Information (Kashiwagi, 2002)

2.2 Telecommunication Networks

Most companies, especially in construction still rely heavily on traditional forms of communication mediums (such as phone, fax, and radio). For a successful exchange and sharing of information, data and information must also be communicated by powerful communication media and devices. In this section, several wire or wireless communication mediums are discussed.

2.2.1 IP addresses and Ports

The Internet can be regarded as a packet-oriented global network. In general, the communication protocol (TCP/IP) is the most common networking format for the client-server applications like HTTP, SMTP, and FTP. The Internet Protocol (IP) offers the

primitive transport packets from one node to another. Each IP packet encloses a header that includes a source and target address. These addresses are recognized as IP addresses. Terminal Control Protocol (TCP) is a layer that stands on top of the IP layer, being accountable for the transmission of data, command, and status packets. The IP address that can be utilized for private networks are listed below:

- (Class A) 10.*.*
- (Class B) 172.*.* through 172.*.*
- (Class C) 192.*.*

The Class C address is the most common, while the Class A and Class B ranges are suitable for large-scale networks. This private address allows an additional range of addresses to be generated using a public IP address. However, these addresses are not routable on the public Internet without going through a router which affords the port forward function.

At any certain time, a network node might have several connection points with various devices and machines around the network. This means that a way of tagging the different connection points is necessary so that they can be differentiated. The scheme used is to assign a logical port number to each node of a connection point. Port numbers are employed to identify logical connections which carry long-term communication. The following Table 2.2 lists some of the most commonly used ports.

Table 2.2 Commonly Used Ports

Protocol	Usage	Port
FTP	File Transfer Programs	21
SMTP	Outgoing mail	25
HTTP	Web content	80
IMAP4	Incoming mail	143
Telnet	Remote computer	23

2.2.2 Wireless Wide Area Networks (WWANs)

Shin et al. (2004) classified wireless transmission channels into five types, that is, circuit-switched cellular modems, specialized mobile radios using packet switched wireless data systems, packet switched cellular modems, wireless local area networks, paging systems, and satellite based data communications.

Wireless Wide Area Networks (WWANs) covers a much more broad area than wireless LAN. According to Fisher and Wang (2002), today's most wireless data links in the U.S. takes place across conventional 2G (second generation) Personal Communication Networks (PCS). The transmission speed provided by 2G systems is still quite limited, offering actual data rates up to 20Kbps. With the advent of 3G networks, communication speed can reach 2Mbps in fixed applications, although most commercial deployments offer actual transmission rates closer to 100Kbps in mobile environments. Although the third generation (3G) wireless technology has not yet been fully implemented throughout the world, the world's leading companies in this market, SAMSUNG in South Korea are already laying the groundwork for fourth generation (4G) technology.

With the rise of next-generation mobile technologies embraced the Internet protocol (IP) technology, 4G services will be in operation around 2011, and 4G speeds could be up to a maximum of 100 Mbps to provide true interactive multimedia capabilities, such as video conferencing, to the handset (PSWN, 2002).

2.2.3 Satellite Networks

Construction sites positioned in remote areas are often not able to easily reach terrestrial communication links (Meissner et al. 2001). For three decades, satellite communication has been used as an effective data link to allow people at remote sites to connect to a land-based network (e.g., Internet).

Recently, Constructware has made a contract with ViaSat Inc., a supplier of satellite-based Internet services, to provide Internet-based project management applications to remote jobsites via satellite links.

Satellites are also utilized for GPS (Global Positioning Services) technologies. By using this technology, QUALCOMM Inc. offers wireless communication and satellite positioning tools to better manage delivery vehicles and equipment. Their nationwide two-way satellite wireless links allow users to rapidly monitor vehicle locations, communicate with drivers, and protect cargo at anywhere.

As one of their European projects, Meissner et al. (2001) developed the COSMOS (Construction Sites Mobile Operations Support) system that supports seamless information flow between sites and headquarters as well as within a site via satellite links.

The system consists of a satellite and its upstream wireless network and several Web-based applications for processing messages and real-time audio and video.

In comparison with terrestrial networks, the satellite link has a higher packet error rate than other transmission links (e.g., fiber), resulting in a long round-trip time. Satellite transmissions are also affected by both terrestrial and space weather (Thom, 2004).

However, satellite communication service is expected to become more prevalent in the remote construction environment in the near future.

2.2.4 Wireless Local Area Networks (WLANs)

WLANs open the door to all possibilities for capturing data in a constantly moving construction site and transferring the captured data to an off-site office, using many types of wireless devices such as personal digital assistants, laptops, and other wireless devices.

VTT (2004) forecast that in the 2004-2008 timeframe, WLANs would be the popular technology for building wireless applications. VTT foresaw that for short-haul wireless links, the data transmission rates would rise up to 50 Mbps in the near future and that for mobile users, the speed of up to 100 Mbps would be possible by 2012.

WLANs are considered the next generation of data networking (VTT, 2004). Small networks of several devices are referred to as WLANs, while more global wide networks are referred to as the Wireless Wide Area Networks (WWANs). Other basic types of wireless networks include the Wireless Personal Area Networks (WPANs), the Wireless Metropolitan Area Networks (WMANs), the Wireless Body Area Networks (WBANs), and the Wireless Vehicular Area Networks (WVANs).

There are two types of WLANs: infrastructure WLANs and ad-hoc WLANs. The infrastructure WLANs are most common implementation of 802.11 networks where the wireless devices are associated and connected to a wired backbone network such as 10BaseT Ethernet via access points. While WLANs provide some key benefits, including mobility and scalability, they are currently much slower than wired LANs and vulnerable to attacks by hackers.

2.2.5 Wi-Fi (Wireless Fidelity) Standards

According to Nuntasunti (2003), Wi-Fi (Wireless Fidelity) is any type of 802.11 network technology that connects computers or wireless devices compatible with Institute of Electrical and Electronic Engineers (IEEE) 802.11x standards. Despite different manufacturers, any products tested and approved as "Wi-Fi Certified" are interoperable with each other. Until now, IEEE has approved four Wi-Fi standards such as 802.11, 802.11a, 802.11b. and 802.11g.

2.2.6 Assessment of Wireless LAN Benefits

In 2001, Cisco Systems and NOP World Technology conducted a benchmark study to assess the benefits of wireless LANs. Two years after this original study, NOP World Technology (2003) explored quantitative research to find the positive benefits of wireless LANs. According to their study, on an overall level, over 12% of 603 U.S. organizations (100+ employees) already either piloted or deployed wireless LAN infrastructure. Among the organizations, the education sector continued to have the highest WLAN

penetration at 29%. NOP World estimated the perceived benefits of wireless LAN use. The overall mean number of hours saved per day by using the wireless LAN was revealed to be 1.29 hour. Taking into account this time saving and a reported average salary of \$80,000, the annual cost savings can be estimated at almost \$14K per user.

2.3 Information Modeling Methods in Construction

An information model is a means to show how people and related entities presently communicate and what data and information is shared between participants in construction projects. This is an important first step for building a shared data resource.

There have been many studies investigating how to model information resources. Entity-Relationship (ER) is an effective modeling tool used to define the architecture of database systems. Gornik (2003) explains the key concepts of ER modeling and defines how Unified Modeling Language (UML) can be employed by developers to develop ER models. Unfortunately, ER modeling does not use the semantic relation in representing ER diagrams.

On the other hand, UML is a widely accepted modeling language used by many developers that is well suit to the graphical representation of ER diagrams. Sowa (2002) defined Unified Modeling Language (UML) next generation language created by the Object Management Group (OMG), a non-profit organization that creates and maintains software industry specifications for interoperable business applications. The UML have been recognized as a successful modeling tool in representing large physical complex systems, especially at the architectural level. The use cases diagrams represents the

functionality of the system from the user's point of view, while the sequence diagrams, activity diagrams, and statechart diagrams represents the internal behaviour of the system. Even though UML has a great benefit in that it produces meta-models and their graphical representations, it lacks agreed-upon formal semantics. UML is usually less expressive than formal ontology languages such as DAML+OIL and Web Ontology Language (OWL).

Another modeling language for describing information structures and associating them with resources is Topic Map, ISO standard (ISO/IEC 13250). The Topic Map is a representation methodology of information used to depict and search information objects. A Topic Map can function as a linking pin between disparate information objects, allowing all of the objects related to a specific concept to be connected with one another.

A Topic Map is composed of topics, associations between topics, and occurrence. A topic is a combined information object that serves as a portal to which everything about the subject that the topic expresses is linked. A topic occurrence is a resource announced to include some sort of information about the topic under condition that it is of value under certain considerations. Topic Maps are proved valuable tools for indexing complex information structures, however they are not suitable for representing rich ontology due to the lack of inherent detailed semantics (Bechhofer, 2002)..

2.4 Information Standards in Construction

Several international standardization efforts have been undertaken to address these interoperability problems between diverse hardware and software systems (i.e., global

positioning systems and radio frequency identification sensors).

To date, there are no clear and straightforward choices for neutral data formats, although several organizations and standards are under development. The following are included among other efforts.

2.4.1 Standard for the Exchange of Product Model Data (STEP)

Launched in 1983, the Standard for the Exchange of Product Model Data (STEP) is a series of standards under development by the International Standardization Organization (ISO). Based on Product Modeling concepts, STEP is a worldwide effort to build second-generation data exchange standards via application protocols, Integrated Resources (IRs) (Gallaher et al., 2004). This neutral data format helps decrease interoperability costs and enhance quality throughout the lifecycle of the data.

2.4.2 Industry Foundation Classes (IFCs)

The International Alliance for Interoperability (IAI) is a world wide initiative to publish standards for facilitating data exchange between software applications throughout the product life cycle within the domains of Architectural, Engineering, Construction, and Facilities Management. Industry Foundation Classes (IFCs) are developed by IAI as critical data elements to specify how building components (such as doors, windows, and walls) should be expressed electronically across disciplines with no loss of information (Crowley, 1998). IFCs are used to build an accurate data model that establishes an object-oriented database, with widely known features from IFCs library.

2.4.3 CIMSteel Integration Standards/Version 2 (CIS/2)

CIS/2 is an electronic data exchange format through which stand-alone programs can exchange engineering data related to structural steel projects. By providing a neutral data format, CIS/2 allows software vendors to make their applications mutually interoperable. CIS/2 has been applied in design, manufacture, and erection applications to facilitate the electronic transfer of information among all parties of the supply chain involved in structural steel construction.

2.4.4 Foundation for Intelligent Physical Agents (FIPA)

Formed in 1996 to produce software standards, the Foundation for Intelligent Physical Agents (FIPA) is an international group that is dedicated to promoting the interoperability of heterogeneous agent-based applications. To support this, FIPA focuses on creating agent standards that range from system architectures to communications languages for expressing messages and interaction protocols.

2.5 Logistics Concepts in Construction

Logistics has been one of the focus areas to improve the productivity of the manufacturing industry. Activities such as factory storage, shipping, and on-site storage, as well as related management activities (e.g., procurement) are considered the main aspects of such logistics.

Wegelius-Lehtone (2001) defined logistics to be “all activities relating to the procurement, shipment, storage of goods, and the movement of related information through the organization and its marketing channels in such a way that current and future profitability are maximized”. He noted that a logistical perspective is regarded as a solid basis for improving productivity in the construction industry. Every construction project can be illustrated as an engineered-to-order delivery process where all the parties along the logistics chain are engaged (Figure 2.2).

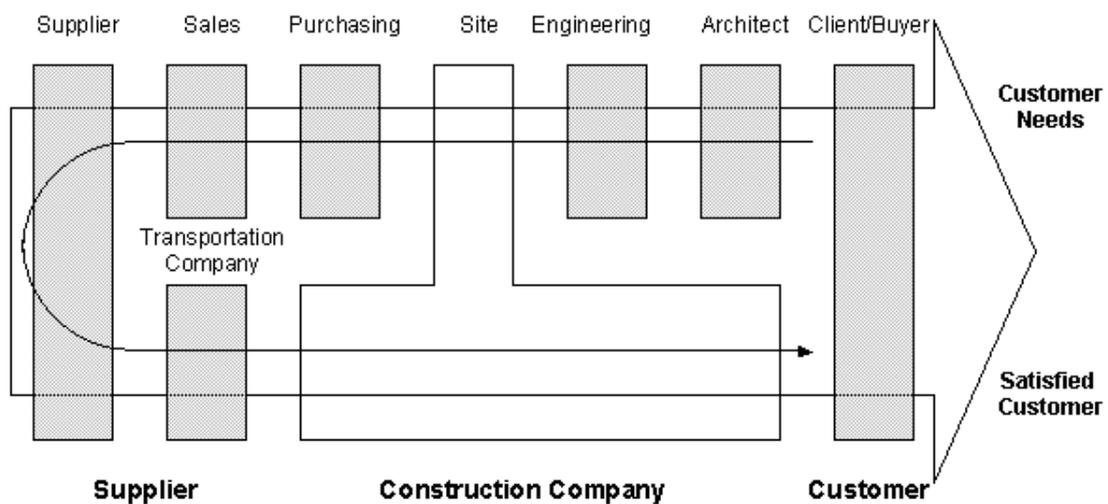


Figure 2.2 Order-Delivery Process of the Construction Project (Wegelius-Lehtone ,2001)

2.5.1 Physical Logistics

From the above logistics definition, two major parts: “physical logistics” and non-physical (can be referred as “information logistics”) can be categorized.

Jang et al. (2003) split physical logistics functions in construction delivery into two parts: supply logistics and site logistics. Figure 2.3 depicts the construction logistics milestones. Supply logistics are relevant to tasks that may occur in the production process. These tasks include the supply planning, transportation, and on-site storage. Site logistics is related to physical material flow on the jobsite such as shakeout and material handling. The site logistics also encompass the site layout plan and equipment mobilization as well as delivery conflicts among various suppliers relevant to the on-site activities (Jang et al., 2003).



Figure 2.3 Construction Logistics (Jang et al., 2003)

2.5.2 Information Logistics

Information logistics addresses how and where data has to be deployed to be close to where it is needed (Michel and Reiher, 2001). It is regarded as part of the overall logistics concept. Soibelman and Caldas (2000) defined information logistics in construction industry as “the process that plans, maintains, tracks, monitors, and controls the flow of information when it is created, processed and reused within design organizational processes”. Information logistics should be well designed to facilitate the

productive use of information as well as assure that the accurate and relevant information would be at the right place at the appropriate time and with the required quality. Without better information logistics, optimizing physical logistics beyond a certain point is impossible (Mellyn and Groeve, 2000).

2.5.2.1 Pull-Push Concepts in Information Logistics

The main difference between push and pull technologies lies in who is initiating the transaction. This action is either started by the information receiver (pull) or by the information sender (push). Figure 2.4 depicts pull and push concepts, respectively where “client” designates user’s computer. It has been long argued that push has more advantages than pull, since it offers tremendous scalability. However, the disadvantages of the push process are that users must always listen for connections.

Acharya et al. (1997) maintained that pull-based technologies are more favorable because they let users to play an active role in acquiring the information they need, rather than depending on the schedule of a push-based server. However, there are two evident weaknesses to pull-based technologies. First, the server should impart users with a back channel over which to transfer their requests. In some wireless network conditions, this back channel can impose significant overhead to the network. Second, the server must be interrupted constantly to deal with pull requests. The combination of push-based data delivery should be well balanced for efficient data dissemination.

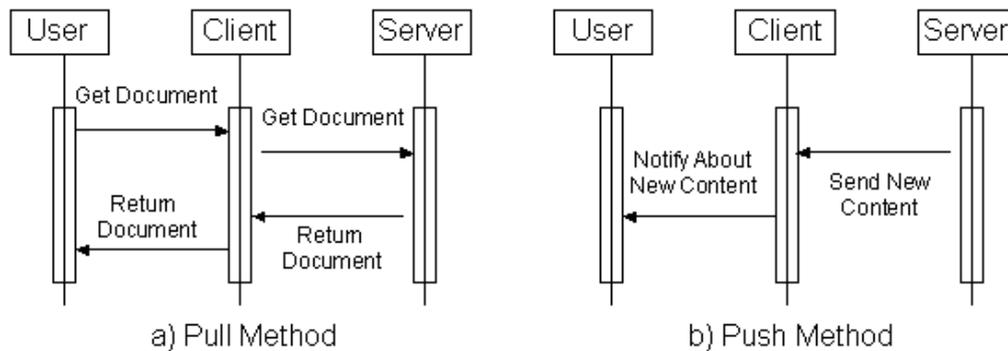


Figure 2.4 Pull and Push Concepts (Kapyla et al., 1998)

2.5.2.2 Just-In-Time (JIT) Information

In the late 1900s, at the Toyota lean manufacturing plants, a Just-In-Time (JIT) inventory system was brought in to substitute for the traditional Just-In-Case (JIC) inventory systems which just stock inventories based on long run production (Hoyt, 1996). JIT inventory management identifies demand for a given product to specify when a product has to be produced. The use of demand-pull allows for producing only what is required by a company at the right time and in the right quantity (Cheng and Podolsky, 1993). In this way, the use of demand-pull can minimize unnecessary inventory, which would otherwise to be overstocked.

Kashiwagi (2002) proposed that JIT technology can be applicable to the management of information. He stressed that just like inventory, information should be minimized and the endeavor to manage the information must be kept to a least amount. JIT usage leads to the following conclusions: 1) only necessary information must be collected; 2) handling of the information should be kept to a minimum; and 3) the performance of a project is dependant on the proactive role of knowledgeable workers.

2.6 Semantic Interoperability

Interoperability is defined as “the ability of software and hardware on multiple machines from multiple vendors to communicate meaningfully” (Netdictionary, 2005). Most software applications (i.e., project planning, cost budgeting, and project scheduling) used in the construction industry has been developed, however the improvement of electronic information exchange has not been improved much, because each application uses its own data structure and format. This leads to high interoperability cost related to information exchange in the construction industry. With the increased use of software applications in the construction sector, an issue of interoperability cost has been exacerbated among the multi-disciplinary groups (Shen et al., 2002).

Early efforts to get over incompatibility problems between software/ hardware applications were focused on the syntax of specifications, but not enough for information exchange between applications using their own platforms, data structure, and terminologies.

The importance of semantic interoperability was highlighted by Gallaher et al. (2004). The need for semantic interoperability has been further focused as the need for data exchange has changed from static data exchange to dynamic within heterogeneous system environments (e.g., Internet). The Open GIS Consortium (OGC) described a difference between syntactic interoperability and semantic for each interoperability issue. Syntactic interoperability ensures that there is a technical connection which means that

that the data can be exchangeable between systems. On the other hand, semantic interoperability makes certain that the content are fully comprehended in the same way in both applications.

At present, there are no solid standards in the construction industry that can address the semantic interoperability described above. Currently, IFCs, CIS, and STEP have mainly focused on syntax interoperability. Hence, currently the burden of semantic interpretations bears heavily on users (Karimi et al., 2003).

2.7 Machine-to-Machine (M2M) Communication

Beginning in the mid-1990s, the M2M market had also been known as pervasive Internet, telemetry, telematics, and remote monitoring (M2M magazine, 2005). Machine-to-Machine communication is also defined as consisting of telematics and telemetry (Kviselius, 2002). Kviselius indicates that telematics is the remote control of machines, while telemetry is the remote monitoring of and gathering of data from machines.

According to e-principles (2004), telematics means information services delivered over a distance using telecommunications networks, while telemetry literally means measuring from a distance. The telemetry implies one-way communication from a sensor to a control unit for measuring parameters like temperature and wind speed.

In 2002, e-principles reported that an estimated 6 billion microprocessors were embedded in millions of machines and devices operating all around us. In the near future, RFID (Radio Frequency Identification) is expected to occupy an important position in M2M applications. Some RFID applications started to be underway to track livestock

and improve logistics in retail and manufacturing industries, but not within the construction sector because it is a relatively high cost compared to Barcode. Nevertheless, RFID is coming into increasing use in industry as an alternative to and extension of the bar code. Many of these sensors and devices would gain value if they need to be constantly monitored from much farther distances by utilizing the latest wireless and Internet technologies (e-principles, 2003).

For example, one construction company in Texas and California has begun to use telematics technology to monitor its remote equipment operations: 1) Equipment location, 2) travel direction, 3) road speed, and 4) ignition time. In this way, M2M applications can link construction equipment such as an excavator or grader to its owner, supplier, and maintenance company. This linkage can allow any of the above organizations to receive the exact location, operation environment, and performance of the construction asset in real time.

VTT Roadmap for Network Technologies and Services Technology Review (2004) brought up issues in Machine-to-Machine (M2M) communication. VTT stated that M2M is not highly ranked in their major roadmaps and not all of the interviewed people were confident about the importance of M2M. As a key enabler of M2M, standards for the exchange of data and information between various types of entities such as people, organizations, and machines is necessary to the integration of information and knowledge resources.

In addition to standards, communication protocols between various types of entities should be developed to automate communication processes and simulate human

communication at various layers of interaction. M2M will provide significantly more capability for automated communication, but also greater flexibility to allow for intelligent human-machine interactions.

2.8 GIS/GPS

A Geographic Information System (GIS) is a type of software application, which maps position data of an object with associated descriptive information about that object. The primary purpose of the GIS is to store, query, and display both spatial and non-spatial data. GIS is commonly used in many industries as a problem-solving and decision-making tool (Kuryk, 2000). A GIS is comprised of a database and a map. Coordinate data is retrieved by the database and then displayed with relation to objects using the mapping and searching engine.

A Global Positioning System (GPS) is a satellite navigational application for providing accurate geographical position measurements. A location is calculated by trilateration, where three satellites are used for locating and a fourth to synchronize time. A precise positioning using a GPS receiver at reference points requires corrections of relative positioning data for remote receivers. In this case, a Differential GPS can be used to ensure higher accuracy; it is capable of superseding a bias error at an unknown location with the measured bias error at a known position.

The data obtained from GPS may be utilized in a GIS system. Once GPS data is processed, categorized, and imported into a GIS system, a GPS can query and display

any data associated with GIS data based on the same geographic referencing system (Kuryk, 2000).

By integrating the two technologies, the possibilities are endless. For example, transportation vehicles are already taking advantage of GPS, incorporating them with a GIS navigational map that provides drivers with real time information on the alternate routes. In automated construction, the idea of providing the machine (i.e., grading machine and backhoe) with three-dimensional data about the position in space and distance to a target position to control the spatial scope of its work is coming into reality (Recalde, 2004).

GIS/ GPS technologies are expected to be used more often in the construction industry to solve problems and make decisions in development, design, project management, and construction.

2.9 Value Assessment Schemes

The following section will review briefly concepts established to determine managerial values both economic and non-economic.

2.9.1 Classic Definitions of Economic Value

Glyn (2002) provides a concise summary of the early value concepts. In primitive economies, people were already engaged in a barter system to exchange goods, using negotiation to establish equivalence in value. According to Wikipedia, “commodity currency such as gold, silver, and copper coin was the first form of money” and used as

mediums of exchange. Later, the commodity money evolved into the modern forms of paper currency and non-precious coinage.

Today, prices for goods and services provide a monetary value that equates the use of those resources to generate revenue or benefits. While the price equates to cost, the benefits can be more difficult to assess because they are affected by external economic factors, such as the size of investment, unemployment rate, fluctuating interest rates, inflation rates, etc. Nevertheless, efforts were made to quantify the value of goods and services, using mathematical model. To determine the economic value of goods and services, a mathematical economic evaluation has to be established. AACE (1999) and others grouped the model into: a) Non-Discounting Methods of Evaluation (Payback Period, Return on Investment, and Break-Even Analysis); and b) Discounting Methods of Evaluation (Net Present Value, Benefit Cost Ratio, and Internal Rate of Return).

2.9.2 Evolution of Managerial Value Concepts

The disadvantage of the mathematical method is the fact that both benefits and costs must be assessed in quantifiable terms (e.g., money). Values are not only quantitative in nature, but also incorporate various qualitative items. Defining qualitative values is very subjective since it is influenced by personal preference such as wants, needs, benefits, function, and objectives. As a result, a managerial value system has to encompass not only economic, but also social, political, aesthetic, religious, and intellectual values (Spranger, 1928).

Park (1999) emphasizes the need to categorize value definition according to the two perspective of sales or trade. Park offers two quantitative formulas: Value = Function/Cost (1); and Value = Benefits/Price (2). Equation (1) reflects the perspective of the product supplier and equation (2) that of the customer.

More recently, Pohlman and Gardiner (2000) went even further and proposed the integrated value management approach called Value Driven Management (VDM). VDM emphasizes eight important value drivers that impact organizational and individual decision making: a) External, b) organizational, c) employee, d) customer, e) supplier, f) third-party, g) owner and h) competitor. Each value driver is interrelated and overlaps with others. Similar to the supply chain concept, if any of the value drivers gets out of balance, the entire value system will become unstable, or even may fall apart. The systematic use of Value Driven Management supports an intricate process of trading-off and careful sensitivity analysis before final decisions are made.

2.9.3 Management with Changing Values

Values as defined by the VDM can change over time even during implementation of a decision. In order to control the impact of such changes, the concept of Value Management (VM) has been applied.

VM is the umbrella term for all studies employing Value Engineering (VE) and Value Analysis (VA) methodology to maximize the value of a project, item, or service (AACE, 1999). VE encompasses all proactive and highly structured forms of decision analysis tools during development time. VA is a reactive methodology to a partially

complete or complete project. For example, Table 2.12 represents value methodology being used by WSDOT for highway design. VM works through an established set of procedures, the VM job plan. The VM job plan includes pre-study and post-study phases, as well as the value study itself, which is composed of eight phases.

Table 2.3 Value Management Phases (WSDOT, 1999)

VM Phases	Description
Selection (pre-study)	Selection of the right projects, processes, or elements
Investigation	Background information, function analysis, team focus
Speculation	Creative, brainstorming, alternative proposals
Evaluation	Analysis of alternatives, life cycle costs
Development	Develop technical and economic supporting data
Presentation	Present recommendations and team findings
Implementation (post-study)	Fair evaluation of proposals, implementation plan
Audit (post-study)	Review of completed results and awards.

2.10 Summary of Literature Review

This section highlights key issues which are related to the topic of this thesis.

1) Many existing technologies that aid in construction process automation are limited in their use by a lack of construction industry standards supporting interoperability between various hardware and software systems. To date, there are no clear and straightforward choices for neutral data formats, although several organizations and standards bodies are developing them. Currently, IFCs, CIS, and STEP have mainly focused on syntax interoperability. At present, there are no standards in the construction industry that can address the semantic interoperability.

2) The majority of contributions that address information flow problems in the construction industry have focused on organizations. The field level application to be able to acquire the knowledge of the state of information from the various process units rarely exists today in the construction industry. Recently, FIATECH started field trials to embrace RFID and GPS in a realistic construction environment to significantly improve the efficiency associated with material management. It is expected that the technologies will be more likely adopted by the construction industry, encouraging lower costs in the future.

3) In recent years, with huge advances in computer fields, IP-enabled ubiquitous computing and new emerging wireless services like 3G, Bluetooth, and WLAN have opened the door to finally address the many deficiencies that are related to the lack of sufficient data and information. However, these services' application has been little exploited in construction sites. Coupled with robust and low-cost sensors, wireless local area networks (WLAN) are expected to become the next generation of data network, thereby increasing operative efficiency and ensuring better integration with the existing project management systems in a distributed construction environment.

4) With the rise of the increasing use of low cost wireless networking, there are now growing opportunities for the wireless Machine-to-Machine (M2M) communication and its applications. However, to date, the benefits of M2M technology have not been

recognized by individual companies or by the construction industry as a whole. Potential financial benefits and industry's opportunities need to be explored to apply this technology to a real construction site. For ubiquitous M2M communication, the IPv6 where each device has its own IP address is a necessary condition in addition to standards for the exchange of information between people and machines or between machines. In the near future, M2M is expected to become more pervasive, opening up an intelligent construction site with vast numbers of Wi-Fi enabled computing devices.

5) There is still widespread use of the manual-based approach in the construction domain. Nevertheless, available technology, especially for replacing the manual-based process, is still not fully utilized in current construction environments. Recently, the adoption of agent technology has been recognized to offer unique opportunities for revolutionary change in effectiveness by utilizing automated functions to capture, store, and transmit data/information quickly and in vast quantities. In the near future, agent technology will be a good basis for supporting a ubiquitous construction environment where millions of IP-enabled computing devices are connected with each other in ad hoc ways.

In the next chapter, the role of agent communication and the generic concept of agent communication will be highlighted. In addition, research, development, and use of agent systems in construction domains and current efforts for and problems in semantic integration applied to the same domain will be highlighted.

3. AUTOMATED INFORMATION EXCHANGE WITH AGENT-MEDIATED COMMUNICATION

The previous chapter presents various technological concepts that have the potential to improve the efficiency of a communication between many construction process units.

One such approach has to be automated information exchange using agent communication technologies. This chapter introduces the role of an agent communication, explains fundamental agent-mediated communication concepts, and highlights current efforts for and problems in semantic integration, and researches and uses on agent applications in the construction domain.

3.1 Roles and Definition of an Information Agent

In most of the various definitions of agent that can be found in the literature, software agents have following attributes (Jennings et al., 1998):

- 1) **Situatedness**: An agent takes sensory input from its environment and it conducts preset actions when something happens which changes the situation in some way.
- 2) **Autonomy**: An agent is able to conduct predefined tasks without direct human intervention, and it has control over its own transactions and internal state.

3) Flexibility: An agent is able to take action in a timely fashion (responsive) and to demonstrate goal-driven behaviors and take the initiative (pro-active).

Among those concepts, our focus lies in the information agents that are capable of acting on behalf of humans in order to accomplish certain tasks specified. These information agents may or may not be computer programs but they basically conduct automating tasks (Cybenko and Brewington, 1998).

For example, information agents could be filtering agents who intend to deal with the problem of information overload by limiting, blocking, and sorting the information coming into an information receiver. Other types of information agents could be monitoring and alerting agents useful for manipulating, controlling, and supervising distributed data sources for specific tasks. In addition to them, searching agents effectively query useful information to satisfy the user's requirements. A key attribute of this agent is that it be able to take on autonomous action.

3.2 Agent Communication Mechanisms

Although agents may perform tasks individually, their interaction and behavior often lead to interactive communication among agents. Once the agents discover each other to further communicate, they must speak to each other using the same agent communication language (ACL), which supports a common syntax and semantics for agent communication. FIPA ACL is one of standard agent communication languages that allow agents to communicate each other. The FIPA ACL specifies communication

between agents and has an associated formal semantics. It consists of five levels as follows (O'Brien and Nicol, 1998):

- 1) Protocol:** defines the interactive rules for structuring the message between agents.
- 2) Communicative Act:** defines the type of communication being processed.
- 3) Messaging:** defines meta-information about the message with identity of agents.
- 4) Content Language:** defines the grammar and related semantics of a message.
- 5) Ontology:** defines the vocabulary and semantics of the terms used in the content.

From the categories above, level 1 provides structure for the dialogue between agents while levels 2-5 are contained in each FIPA ACL message.

In FIPA systems, agents communicate with one another, by interchanging messages. A message is a means of communication between two or more agents. Two fundamental facets of message communication between agents are the message structure and the message transport. A message, as shown in Figure 3.1, provides a standard way of representing meta-information such as the sender, the receiver, the ontology, etc.

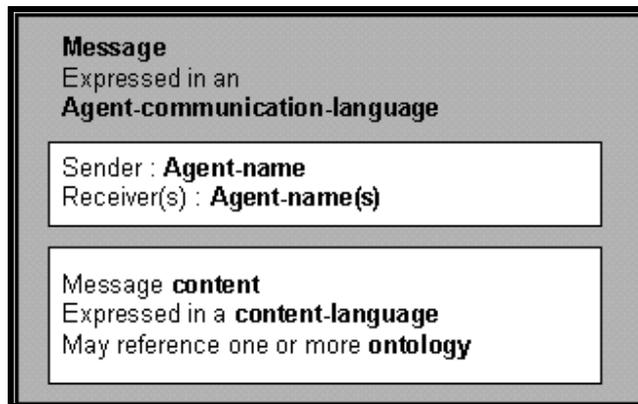


Figure 3.1 Message Structure (FIPA, 2002)

A message is written with an agent communication language (i.e., FIPA ACL).

The content of the message is used to express the actual content of a message in a content language (e.g., FIPA SL). Content may refer to one or more ontologies referenced in the ontology attribute of a message. The messages also include the agent-names of the sender and receiver agents, but do not contain any transport or addressing information. Agent names are unique identifiers for an agent. Every message might have one sender and zero or more receivers.

O'Brien and Nicol (1998) showed how an ACL message works in the following example:

```
(inform
:sender (agent-identifier :name WeatherAgent)
:receiver (set (agent-identifier :name AgentBob))
:content
((weather-forecast :date tomorrow :forecast snow))
:ontology WeatherOntology :language FIPA-SL)
:protocol fipa-contract-net
```

In this communication, the message information includes sending agent, receiving agent, a FIPA ACL performative (inform) as well as the protocol (fipa-contract-net). The initiating agent, WeatherAgent, transmits an inform message to AgentBob. The content of this message is stated in FIPA SL and informs AgentBob that it will snow the next day using an ontology called Weather ontology.

When a message is sent from sender to receivers, it is transformed into a payload and contained in a transport-message as shown in Figure 3.2,. The payload is encoded using the encoding-representation suitable for the transmission.

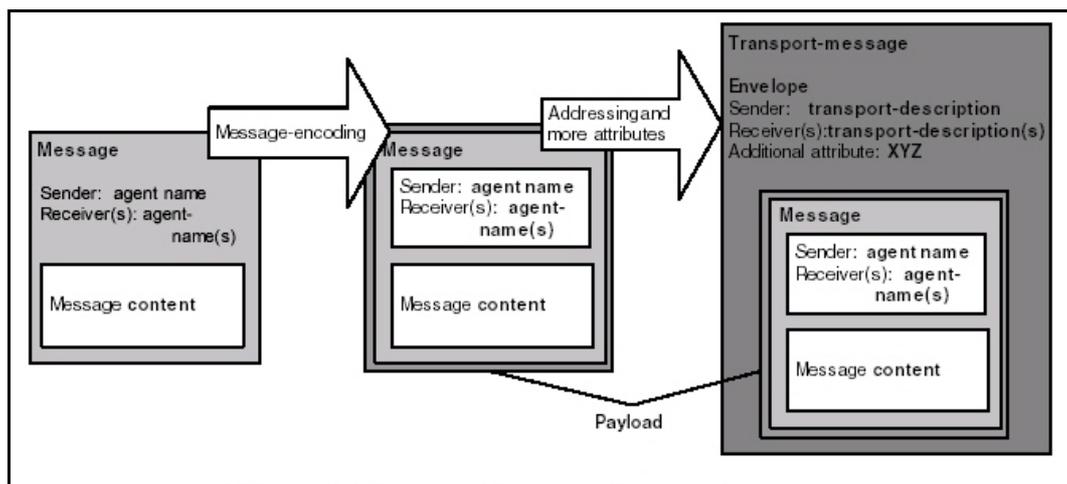


Figure 3.2 Transport-Message Structures (FIPA, 2002)

A transport-message is the object conveyed from agent to agent. It contains the transport-description for the sender and receiver or receivers, together with a payload including the message. The envelope contains the sender and receiver transport-descriptions. The transport-descriptions include the information about how to transfer the

message such as via what transport, to what destination, and how to employ the transport. The envelope can also contain some additional information, such as the encoding-representation, security related data, and other related data.

3.3 Rationale for Explicit Ontologies

Currently, ontologies are widely applied and tested to conceptualize the knowledge of a specific domain, or the technical terms and their semantics used in the same domain. To achieve ontology-based semantic integration, two agents should find out a way to understand the meanings of the terms used in their ontologies (Knublauch and Rose, 2000).

As pointed out by Uschold (2002), an important point about the discussion of semantic representation is whether the semantics in certain applications are explicitly or implicitly encoded, rather than whether the applications have semantics. If two systems, A and B, are able to talk with each other and succeed in transmitting each message, they can be considered to hold shared semantics. If these semantics remain explicit, there should exist a neutral format representing the meaning of each message. However, if such an explicit code does not exist and the applications just communicate by sending program code made by the developer, the semantics are said to be implicitly encoded and this is a strong limit to deployment in an open environment where agents are designed by different computer programmers or companies.

Having explicitly expressed ontologies provides several benefits such as querying for terms and concepts, updating an ontology, extending ontologies, translation between

different ontologies, etc. Semantic integration of heterogeneous information sources in an open environment (e.g., the Internet) may also benefit from an explicit ontology library (FIPA, 2002). In this situation, ontologies may be utilized to define the relation of information content without accessing the underlying data. Such explicit ontologies allow distributed data to be virtually located anywhere. Therefore, the ontologies used by agents need to be built and explicitly expressed in the open system environment in order to enable ubiquitous and serendipitous agent communication (FIPA, 2002).

3.4 Current Efforts for Semantic Integration in the Steel Construction

As mentioned in the previous chapter, the CIS/2 is a neutral data format allowing for seamless data exchange among all project participants involved in steel construction throughout the design, detailing, and fabrication life cycle.

This standard encourages each application to abide by the neutral data format (STEP Part 21) and the neutral data structure (The Logical Product Model 5, CIS Standard Volume 4). An import and export translator should be built into each application to make an exchanging file. The CIS2 manual presents that standards for electronic data used to enable the efficient flow of information could be categorized in two data exchange scenarios as shown in Figure 3.3.

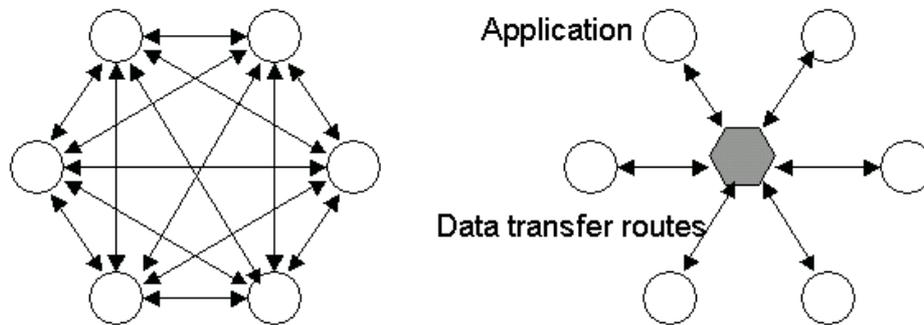


Figure 3.3 Data Exchange Approach Using the CIS Neutral Data Format (Crowley and Watson, 2000)

The left side of Figure 3.3 depicts an option to develop direct one-to-one translators between various applications, converting files from one format to the other. This approach significantly lacks interoperability, causing the cost of translation. If a couple of applications are to be integrated, then direct translation may be appropriate. However, as the number of applications increases, the number of direct translators required is significantly greater, thus soon making them difficult to maintain.

On the other hand, the right side of Figure 3.3 shows an alternative approach to data exchange by using a neutral data format. This approach requires $2N$ number of translators to be developed, thus reducing the number of translators required. Translators for exchanging information between applications in CIS/2 format are developed based on second option, mapping mechanism between the data formats. Nevertheless, in both cases, a translating package cost is added to the software development costs.

The only way to avoid the demand for any translators is for all applications to be developed by using only the CIS neutral data format. However, today complete CIS

compliance for existing application cannot be accomplished without using CIS translators.

3.4.1 Problems in Current Approaches for Semantic Integration

Reed (2002) argued that the CIS/2 standard in steel construction is initially intended to satisfy the needs of on-site steel construction. However, this neutral format focuses on design-centric representations to improve design and make it easy to visualize its problem (e.g., virtual reality simulations), which means the CIS/2 documentation puts more emphasis on the pre-construction phases such as design, analysis, detailing, and shop fabrication. Ugwu et al. (2005) pointed out that this is the reason why the CIS/2 model is not enough to sufficiently represent the features that are able to use for steel erection. This situation often leads to extremely difficult and sometimes erroneous erection due to unexpected interference between steel elements. Although there exist few software that can assist erection planning effort through the subdivision of the structure into several erection zones, the existing approaches hardly manage the information needs required for steel erection at the jobsite (Reed, 2002).

According to Liebich (2004), CIS/2 uses a neutral data schema to make the disparate applications interoperable and thus is comparable to the predetermined ontology effort to agent communication. Liebich commented that the entire CIS/2 data schema exists at the class level and is not enough to provide a complete ontology even though the scope of the classes is extended.

Much of the reasoning capability is derived from the use of ontologies. Therefore, the ontologies associated with the specification of spaces, time, materials, processes, constraints, etc. should be developed. Systematic relationships between these elements allow agents to process their tasks based on reasoning.

Therefore, the development of lightweight ontologies is regarded as a key stepping-stone to the enhanced use of CIS/2 data schema.

3.5 Researches and Uses of Agent Systems in the Construction Domain

Unlike the computer science domain, the researches on agent technology in the construction domain are not active. This is thought to be mainly because the construction industry engages in risk-averting behavior and is more likely to adopt proven technologies. Three studies and their applicabilities to agent systems in the construction industry are investigated and summarized in this section.

1) The application of agent technology in construction domain can have many different objectives. One example of such an agent application is Agent-Based Modeling and Simulation (ABMS), an agent application in which a simulation test bed is set up around a set of autonomous agents that communicate with each other to replicate the real-world case. Chick et al. (2003) conducted a preliminary test to see if the ABMS could effectively mimic real construction domains. To determine the effectiveness of the agent-based simulation, a residential subdivision was selected and modeled using the agent-based simulation environment called StarLogo. StarLogo is a simple agent-based software in which communicative acts associated with agent rules was programmed to

allow predefined agents to interact with each other in their simulated environment. This study proved that ABMS might provide fast answers to the complex real world problems which would be otherwise not capable of being obtained.

2) Negotiation is one of important aspects of the construction process. Ren et al. (2003) developed and tested a multi-agent system for construction claims negotiation called MASCOT where autonomous agents, working on behalf of humans, can directly negotiate with each other in order to resolve construction claims and disputes. The MASCOT was mounted on the ZEUS agent-building toolkit. This study reviews the core negotiation theories, sketches the unique characteristics of the construction claims negotiation, and discusses a suitable negotiation mechanism for MASCOT. The authors reported that the inefficiency in claims negotiation and late participation of the client could be minimized by applying such a system.

3) An intelligent agent can also be used as an assistant to inexperienced design engineers, helping them to solve a number of engineering problems (e.g., constructability review). Ugwu et al. (2005) proposed an ontology development study for constructability review in steel structures. This paper paid much attention to a mechanism for structuring ontology for constructability assessment as well as an experimental study of its practical application for automated learning through the use of rule-based agents. It then proposed constructability ontology able to be used for steel structures and an experimental agent framework for automated acquisition of constructability knowledge. The study showed the fact that an ontology approach can facilitate constructability assessment and relevant decision-making in the construction and engineering domain.

4. THE USE OF DIGITAL AND WIRELESS TECHNOLOGIES IN CONSTRUCTION

A questionnaire survey was initiated with the goal to get a better understanding about the present use of advanced communication technologies as well as the practitioners' perceptions concerning their future. This chapter presents the design of the survey followed by a discussion of the collected data.

4.1 Questionnaire Design

The final questionnaire, shown in Appendix A, was organized in three main parts. The first consists of general questions (e.g., core business area of the represented company) while the second section inquires about the respondents' use of current communication and wireless tools in their projects. The third part was dedicated to elicit "industry's" opinions on barriers and opportunities.

4.2 Survey Methodology and Background Information

The dissemination and collection of the survey was done through the ASCE/CI Committee on Wireless Construction using both paper-based and on-line questionnaires. The survey used a Web survey to answer a questionnaire on the Web while paper questionnaires were sent out to respondents which did not have Web access. Committee members were asked to encourage construction managers to fill out the forms in either

format. The survey was conducted from March 11 through July 30 of 2005. The on-line survey page was created and housed on the East Carolina University's Website (<http://www.tecs.ecu.edu/cm-dept/survey/index.asp>). A total of 70 responses were received of which 15 had to be discarded due to largely incomplete sections. As a result, 55 questionnaires provide the basis for the following analysis.

4.3 Analysis of Key Business Facts

Figure 4.1 shows the distribution of core businesses and company locations for which the survey respondents work. As seen in Figure 4.1-a, 53% of those surveyed perform their business in the area of civil & building construction. Company headquarters covered by the study represent all the geographical area of the United States.

Sixteen were (vice) presidents, four directors, nine project or program managers, four safety managers, four research scientists, twelve engineers, two superintendent, etc.

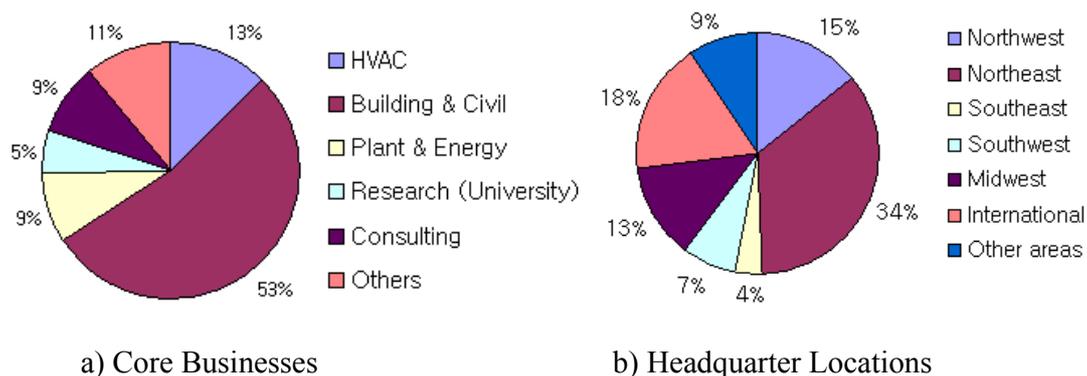


Figure 4.1 Background on Represented Companies

Finally, managers were asked to identify the size of their company by choosing one of four options as shown in Table 4.1. The scope of the survey was focused to the company size with annual sales volume over \$10 million dollars. 35% of all company had over \$100 million in sales last year while a total of 62% has sales in excess of \$10 million. 15 respondents did not answer this question.

Table 4.1 Company Size Distributions

Sales Volume	Over \$100 million	Between \$10-100	Between \$1-10	Less then \$1 million	Unidentified	Total
Number of Company	19	15	1	5	15	55

4.4 Analysis of State-of-Practice

The second section first requested the managers to rate the use of communication channels for their work, especially to request, respond, and distribute information. The rating scale ranges 1 to 3, 3 representing “a lot” and 1 representing “never”. Figure 4.2 depicts overall usage ratings for the listed channels. Usage rate is calculated by adding the scores for one question and dividing it by the maximum possible score for the same.

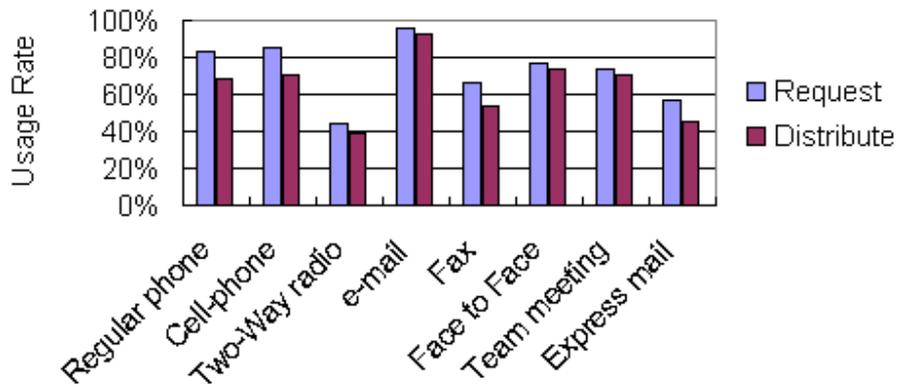


Figure 4.2 Information Request and Distribution Channels Being Used

Two-way radio are the least preferred channels and has been overtaken by cell-phones although regular phones are still in heavy use (83%). With 96%, clearly the most used channel is e-mail, an outcome that might be slightly skewed by the self-selection process caused by on-line survey. What would been a major channel 10 years ago, Fax has dropped to approximately 65%. It did become apparent that no one channel is sufficient to cover all of the respondents' communication needs. The phones and radio, while fast and convenient, are limited to one-to-one communication. On the other hand, the face-to-face meetings allow communication between multiple parties in real time, but it is expensive.

Figure 4.3 underscores the rise of laptops and the “dormant” state of Table PCs and electronic sensors (e.g., a wind speed).

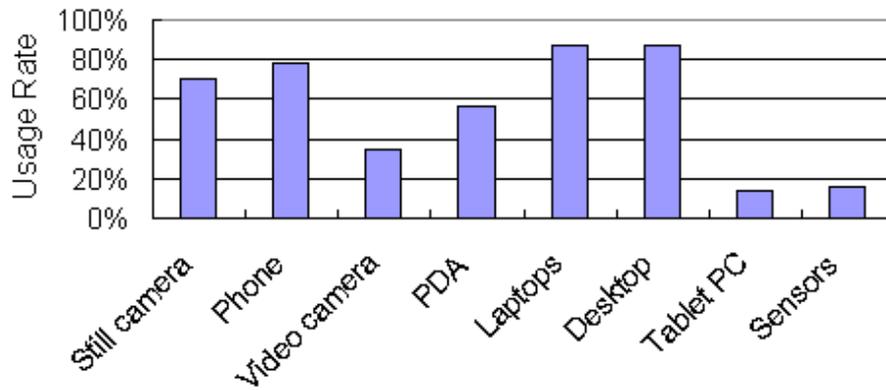


Figure 4.3 Digital Tools Being Used

According to the graph in Figure 4.3, desktop PCs or laptop computers show both a 88% usage rate, followed by digital phones (79%) and digital cameras (71%).

Also included in the section was a important question concerning the use of cutting edge computer tools and means. Highlight in the histogram in Figure 4.4 is the fact that CAD is, with 66%, by far the most heavily utilized application pointed out by the respondents.

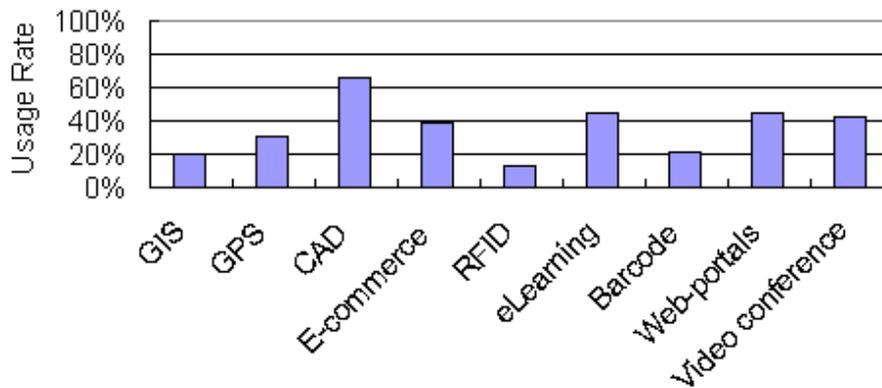


Figure 4.4 Cutting Edge Tools Being Used

Not surprisingly, RFID and GIS are still “underused”. On the other hand, the low usage rate for Barcode and GPS is a big surprise. e-Learning and e-Commerce with approximately 40% show a significant level of usage.

The question related to the use of wireless technologies was presented to practitioners.

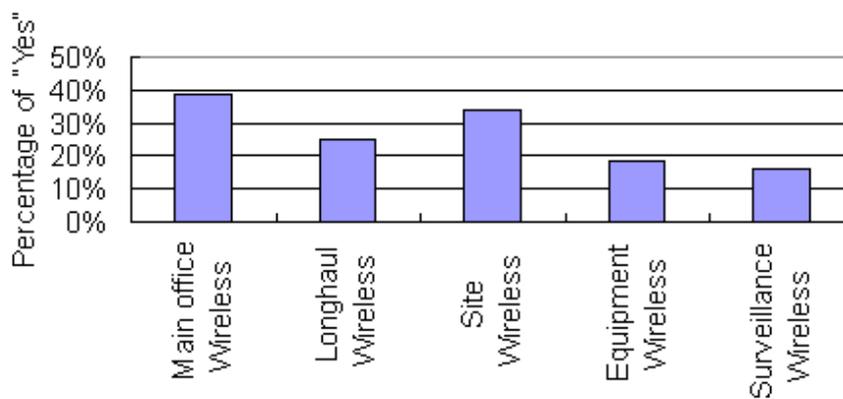


Figure 4.5 Wireless Technologies Being Used

As shown in Figure 4.5, almost 40% indicates that they use wireless networks in main offices and 34% on construction sites. Automated Video surveillance system without cables and persons viewing monitors is being used by less than 16% of the companies included in survey.

4.5 Analysis of Barriers and Opportunities

This section presents results of the third part of the questionnaire shown in the Appendix A. Figure 4.6 features the results of the question most relevant to this thesis. The rubric asked managers to evaluate the values (between 1 and 3) for each of the 14 Web functions available today.

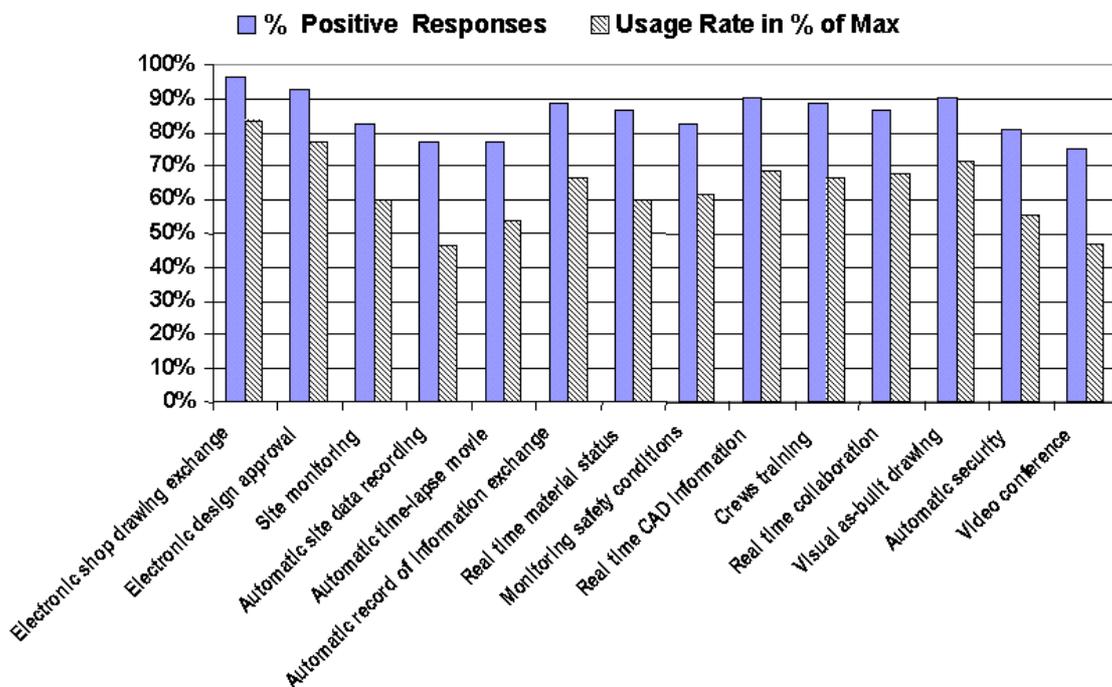


Figure 4.6 Opportunities for Web-based Communication in Construction

It is apparent that in both responses, a document-related group shows higher opportunities than others. This includes shop drawings, a design approval, as-built drawings, and automated record of information exchange. It is assumed that current paper-based approach to document management has a significant problem in the construction industry, leading to a great deal of waste. Second, a data access-related group seems to be less prospective than others. Such a cluster consists of site monitoring, automatic site data recording, automatic time-lapse movie, and real-time material status. Furthermore, another set of opportunities could be categorized to a problem solving group which contains real-time CAD information, real-time collaboration, and video camera. Last could be classified as a site security group. This comprises of safety condition monitoring and automatic security.

44 respondents were asked to identify barriers to the use of wireless technologies that they perceived need to be overcome.

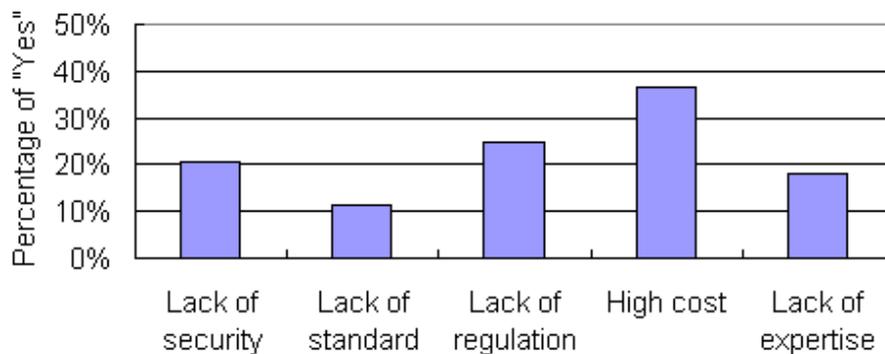


Figure 4.7 Barriers to the Use of Wireless Technologies

Figure 4.7 shows that, with 36%, the cost of implementing wireless technologies is considered the highest barrier. Other obstacles that are likely to affect the use of wireless LAN include lack of security and lack of appropriate regulations.

In Figure 4.8, respondents were asked to check at which areas they have experienced any improvements since the wireless LAN has been introduced. It appears that respondents have experienced more improvements in the areas of service, work flexibility, and productivity rather than security, labor management, and production cost. Respondents are more likely to view service gains as key benefits. It is assumed that the freedom offered by a wireless LAN will bring about work flexibility. It is clear that wireless LANs will contribute to improving productivity, thus increasing efficiency in complex construction environments.

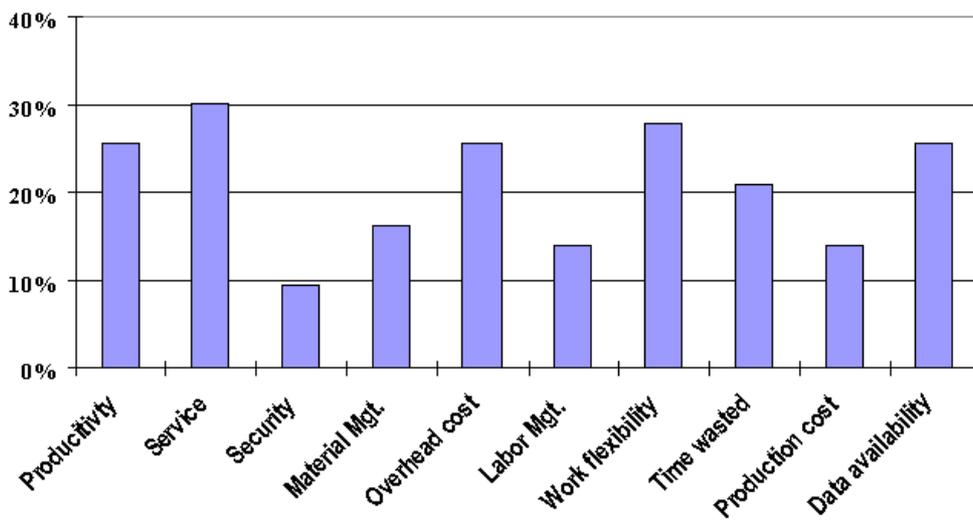


Figure 4.8 Expected Positive Impacts of Wireless Technologies

5. STUDY OF STEEL CONSTRUCTION PROCESSES

As mentioned in section 1.7, research methodology, a structural steel construction site was selected as an experimental case facility. Multistory steel structural plants require repetitive operations and assembly of many structural elements. Those operational characteristics should be treated with more careful consideration and need more control for efficient assembly at the jobsite by incorporating current information and communication technology. The structural steel construction processes of the Cates Project were observed and modeled to represent an overview of the current practices of existing structural steel operations, find out potential productivity problems and sources of waste, and explore the potential possibilities for modernizing current processes.

5.1 Steel Construction Process Overview

In this section, photographs were taken throughout the processes of fabrication, shipping, and erection. Key material brought in during each phase of the steel construction process are briefly described.

5.1.1 Preplanning and Fabrication

At an early stage, the Gilbane Building Co., general contractor and Dave Steel Company Inc., steel supplier, and Harris steel erectors worked as a tightly coordinated team. They worked together to discuss project site constraints to fully set up the crane, as

it defined not only the layout of other temporary facilities but also the flow of many process units. They also determined the steel erection sequence (hereafter called the sequence number), which represents the order in which a zone or section of the structural steel frame is delivered and erected to improve the efficiency of loading, delivery, unloading, and erection. In accordance with the erection sequence information, the steel factory created the fabrication schedule, which meets the general contractor's master schedule.

Figure 5.1 shows the fabricator's shop where structural members were being fabricated and the piece mark labeled on the steel members.

Once fabricated, each finished structural steel member is labeled with a unique piece mark for identification and tracking as well as to locating and orienting each member during erection.

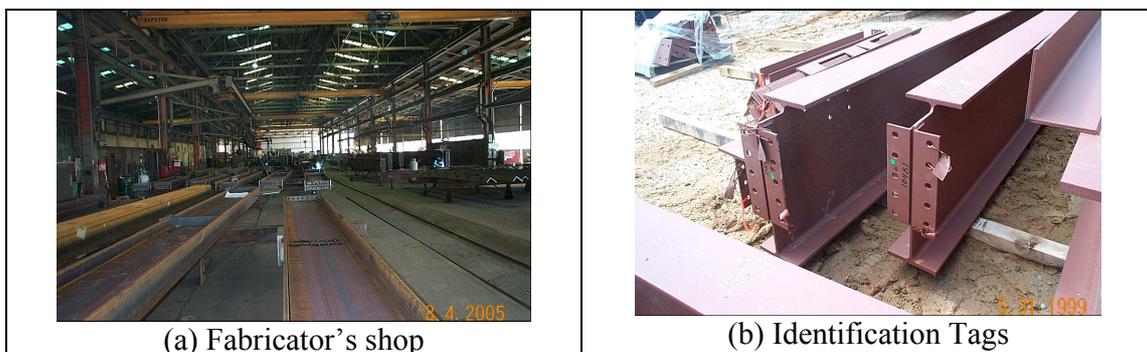


Figure 5.1 Fabrication of Structural Steel

5.1.2 Shipment and Unloading

After fabrication, finished structural steel members were stored in the fabricator's storage yard according to erection sequence. Each segment was loaded on trucks and transported to the jobsite for erection in terms of the steel erector's request during the course of the work. Upon delivery to the jobsite, the fabricated steel members were unloaded to the ground close to their final position. After unloading, shakeout of structural steel members took place. The shakeout involves organizing, spacing, and sorting steel pieces on site so that they can be efficiently erected.



Figure 5.2 Unloading of Structural Steel Members

5.1.3 Steel Erection

In accordance with the erection order prepared by the foreman, the members are then picked up from the laydown area on the site, moved into the final position by a crane, attached to the existing structural skeleton using a minimum of two bolts for each connection, and unhooked from the crane.

Figure 5.3 shows the foreman using the erection drawings to determine the exact order (hereafter called the order number as opposed to the sequence number mentioned in section 5.1.1) in which structural steel members were to be erected. Two steel erectors were lowering the columns for the second tier carefully over the first tier of columns.

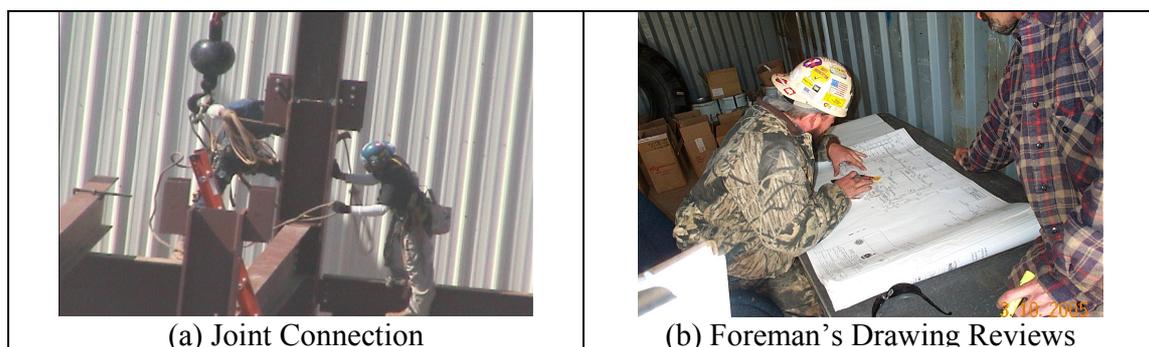


Figure 5.3 Steel Erections

5.2 Model the Existing Steel Construction Processes

Based on the field observation in the previous section, a diagram of material and information flow was presented to represent the flows of information and material throughout the fabrication, shipping, and erection phases. Structural data analysis was used to model the existing processes. This diagram provides us with a guideline of what data the structural steel crew needs to perform a specific task, how data are shared, and where to get those data. This helps us to diagnose existing structural steel construction processes to find out alternative processes. The green colored boxes indicate a data

As seen in the diagram, all information and materials are passed from one party to another via a conventional approach. Key data sources, or “sinks” within a defined system are: 1) foreman, 2) fabricator, 3) ground workers, and 4) connectors.

The next two sections will define the productivity of the current practices and need for improvement.

5.3 Productivity Measurement

All tasks and movements of the steel crews were observed to collect productivity ratings data for structural steel operation. It is not possible to observe and analyze all of the tasks. Therefore, a work sampling technique was introduced to this case for measuring productivity.

According to Oglesby et al. (1989), a minimum of 384 observations are needed to draw statistically sound conclusions at the given condition of the 50% category proportion, 5% limit of error, and 95% confidence level.

It was proposed that the total number of observations was set to 500 for shakeout & unloading process, which were 100 random observations for each worker. The main reason for deciding to take 500 observations is that minimum required observation could be affected under any adverse situations, causing loss of observation data in any case. These observations were spread out over 3 days.

For productivity ratings, all the works were broken down into the three classifications: Effective, Contributory, and Ineffective (Oglesby et al., 1989).

Table 5.1 summarizes the percentages of crew time in all categories of the shakeout and unloading operations. The percentage rate is calculated, dividing the observed number in each category by the total observation (i.e., 500).

It is noted that only 32 % of total crew time was spent on the effective work for the shakeout and unloading operations while the contributory work took 27% of crew time. The ineffective work accounts for 41% of crew time on the average.

Average time spent for (b) work related communication, (c) moving & searching for materials and tools inside laydown area, (i) waiting for a material or equipment or tools, and (k) idle doing nothing amount to 13%, 9%, 12%, and 12% respectively.

These must be the areas to be addressed for productivity improvement.

Table 5.1 Results of the Productivity Ratings

Categories	Items	Percent of Total Number (Shake Out & Unloading)					Average
		Foreman	Erector (1)	Erector (2)	Worker (1)	Worker (2)	
Effective work	(a)	6%	43%	43%	38%	31%	32%
Contributory work	(b) Work related communication	21%	12%	10%	10%	10%	13%
	(c) Moving & searching for materials and tools inside lay down area	1%	15%	15%	10%	6%	9%
	(f) Read document, monitor, and supervise workers	25%	0%	0%	0%	0%	5%
	(g) Get ready to work	0%	0%	0%	0%	0%	0%
	Sub total	47%	27%	25%	20%	16%	27%
Ineffective work	(h) Walking empty-handed	8%	5%	3%	5%	7%	6%
	(i) Waiting for a material or equipment or tools	0%	8%	15%	13%	26%	12%
	(j) Correcting an error	0%	0%	0%	0%	0%	0%
	(k) Idle doing nothing	4%	9%	11%	17%	18%	12%
	(l) Non-work related communication	19%	8%	3%	7%	1%	8%
	(m) Moving & searching for materials and tools outside lay down area	2%	0%	0%	0%	1%	1%
	(n) Brake time	0%	0%	0%	0%	0%	0%
	(o) Non-identifiable	14%	0%	0%	0%	0%	3%
	Sub total	47%	30%	32%	42%	53%	41%
Total		100%	100%	100%	100%	100%	100%

On the other hand, continuous time study involves the measurement of time required to address a specific job under preset conditions. Among all the process, unloading, shakeout, and erection operation were selected for continuous time study. It was proposed that continuous time study be made of an average of five different cycles for unloading & shakeout, and three different cycles for erection operation. This cycle of tasks consists of hooking the member onto the crane, lifting it, positioning it, connecting

it with two bolts at either end, disconnecting the crane, and swinging the crane back to the loading position. The number of times the cycle is repeated equals the number of members to be erected. Table 5.2 summarizes the results of the continuous time study.

Table 5.2 Average Cycle Times (minute: second)

Cycle of Tasks	Erection (1 st Floor)		Shake Out & Unloading	
	Column	Beam	Column	Beam
Find	01:18(12%)	00:52(10%)		
Mark Center		00:37(7%)		
Hook	01:20(13%)	01:19(15%)	00:32(18%)	00:45(33%)
Lift	01:20(13%)	00:55(11%)	01:03(36%)	00:39(29%)
Position (Spacing)	00:42(7%)	01:38(19%)	00:26(14%)	00:26(19%)
Connect	03:05(29%)	01:49(21%)		
Unhook	01:50(17%)	00:24(5%)	00:57(32%)	00:26(19%)
Swing back	00:58(9%)	01:00(12%)		
Average cycle time	10:33(100%)	08:33(100%)	02:58(100%)	02:17(100%)

5.4 Disruptions in Information Flow

Especially, prefabricated materials such as structural steel and pipe spools are required to be installed in a specific order due to structural safe requirements and the complexity of the steel size and shape.

However, shipping, transportation, unloading, and on-site storage do not take into account the erection order of assembly. As a result, a considerable time was consumed locating, sorting, and identifying steel components. Instead of setting the steel directly off the delivery trucks, all the steel was off-loaded and shakeout was done as the steel was delivered. This practice also resulted in double handling of materials in the erection operations.

Once fabricated, the fabricator labeled each steel member with a unique piece mark and a sequence number to identify members quickly and position them at their proper place. However, to make it easy to find materials for erection, the ironworkers marked each piece one more time, with white chalk, the same identification number as the one double marked on the pieces with a metal tag and marker pen at the factory as shown in Figure 5.1. Each steel piece is manually marked the same identification number in three different types of ways, causing considerable unproductive duplication.

Right after unloading, ironworkers marked the center of gravity with a white chalk on each piece to keep the beam remains level when hoisted. This operation would be much more productive if the center of gravity was marked at the factory.

Next, the foreman determined the exact order in which each of the structural steel members were to be erected several times a day and passed it to the ground workers. The ground workers located and identified components with the paper-based information.

As a result, a significant portion of time was spent on ground workers searching laydown areas by hand to identify components. As shown in Table 5.2, searching time for the steel erection of the 1st floor column and beam accounts for 12% (01:18) and 10% (00:52) of the average cycle time (10:33 for column, 08:33 for beam) respectively.

During the observation, it was found that the material and information flow can be lost, disconnected, and distorted while flowing from information sources through information consumers. For instance, ground workers had no idea of when the next sequence of steel elements would arrive. Connectors had no full idea of where each steel element was positioned. The foreman had no idea of the status of a shop drawing

approval and which sequence of steel elements was fabricated and stored at the factory to get ready to ship.

Another information disconnected to workers is weather. Crane safety is often affected by weather events, i.e., high wind, snow, and cold temperatures. Ironically, there were no tools to monitor and predict dangerous wind speed at the jobsite.

It was also observed that most information was acquired through the steel foreman only, which means that information from the foreman to crews at the worksite flowed one way, thus tasks of the construction entities heavily depended on foremen's decisions. As well, the critical information from the field did not flow back to the offices of the designers and constructors in real time. According to the productivity ratings data mentioned in the previous section, the foreman spent most of his time communicating with other workers. Table 5.1 shows that he spent 21% of his time on work related communication (b) and 19% for non-work related communication (l). These are much higher than the average values, 13% and 8% respectively.

5.5 Other Communication Problems Observed

In this section, several communication problems observed in current steel construction processes are highlighted.

1) Communication was important when erecting steel components. The foreman spent a lot of time keeping a close eye on how steel erectors work to avoid potential connection errors in the steel erection. The foreman occasionally could not see the member being connected, depending on other structures, long distances, and light

conditions in our case project. Consequently, he continuously moved on to have a better position to keep track of the activities of workers engaged in operations during the visual observations, leading to wasted time going from one place to another.

Similarly, when erecting steel components, two ironworkers used hand signals to talk with the crane operator to avoid accidental contact with nearby steel structures. Even though hand signals are an excellent method for communicating with crane operators, it is often difficult for a crane operator to get a clear view of the load, thus increasing the risk during crane operations.

2) It has been determined in discussions with Mr. Tim C. Heffner, Vice President for Dave Steel Company, that most of the delays associated with the steel process of supply are encountered during approval stage of the shop drawing. This situation occurs, due to the improper management of drawings of all parties involved. During the approval process, many weeks are wasted due to the movement of hard copy drawings from one party to the other.

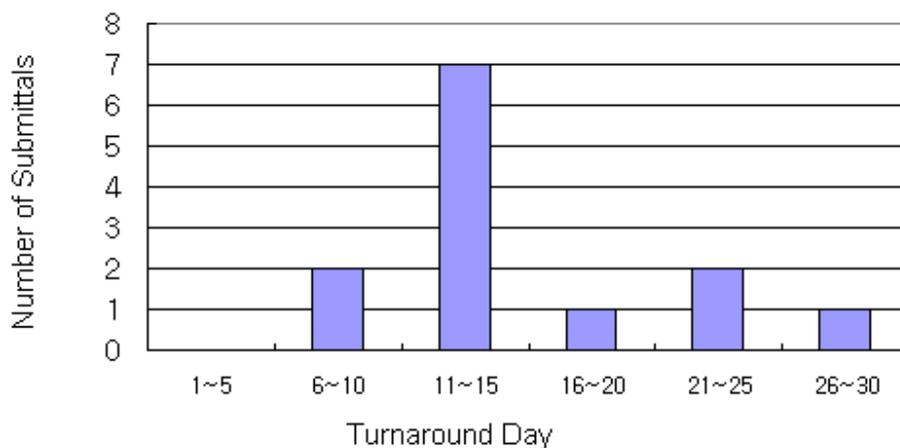


Figure 5.5 Submittals Turnaround Time

Figure 5.5 shows the analysis of number of submittals in terms of the turnaround times. The average review time was 15 days from time of receipt at the structural steel designer, RMF Engineering, Inc. This is an unavoidable delay if the current paper-based process is kept on.

3) According to our case project, the two trucks arrived at the work site at approximately 7:30 A.M. for the first delivery. However, they could not off-load the materials with the crane because a crane operator and workers in charge of handling the load was not available. At that time, in the Gilbane's office, they were taking 1 hr 50 min of safety training course with discrimination video which addresses safety requirements related to steel erection activities and reviews the various kinds of discrimination that can occur in the workplace. Then a crane inspection was performed during 1 hour at the jobsite to test a critical load. Two loads of steel could not be unloaded until 09:50 A.M. when they had finished all safety training requirements.

4) Currently, when a problem aroused at the job site that cannot be resolved at the field office, the field office engineer submitted a request for information (RFI) to the technical engineering representative in the structural steel designer, RMF Engineering. RFIs were sent via fax with a sketch and a reference in the drawings. If photographs were

included in the RFI, they mailed them to the designer by Federal Express. This led to a delay in RFI turnaround times.

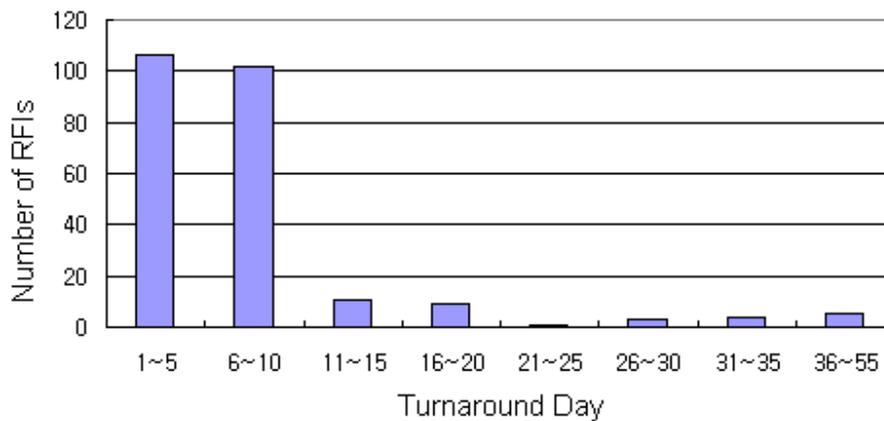


Figure 5.6 RFIs Turnaround Time

Figure 5.6 visualizes number of submittals in terms of the submittal turnaround times. The average turnaround time for an RFI was 7 working days from the time of receipt at the structural steel designer, RMF Engineering, Inc.

5) During the entire construction phase, an inspection engineer working for Stewart Engineering Inc. had continuously documented what was happening at the site, pointed out areas in which the contractor is not following the drawings and specifications and confirmed that contractors corrected any work that was substandard in quality. After inspection, this information then was taken back to the office and delivered to the owner to report the state of the work, making a long and time-consuming journey.

6. DESIGN A NEUTRAL DATA FORMAT

Many process units often operate in isolation and do not effectively communicate with other units both internally and externally because the names and definitions of data and data formats normally differ between agent applications, construction machinery, and devices that are in use.

In this chapter, the neutral data format for structural steel erection process is designed to resolve the above problems and guarantee the interoperability of data.

6.1 Development of A Data Flow Diagram

In order to develop a neutral data format for structural steel construction processes, “To-Be” data flows diagrams were determined based on the field observation in the previous chapter. In the data flow diagram as shown in Figure 6.1, key issues that were addressed include real-time piece tracking, retrieval of the position and orientation information of fabricated elements, and the development of a real-time weather alarm system for a crane operator.

When wind speed from remote sensors is more than 20 miles per hour, information flow “push wind speed and direction” is triggered for a crane safety. In addition, when the steel component’s identity can be read directly through a portable RFID reader, the erection sequence and position information of each piece in their final location are automatically extracted from the common database through wireless networks in real

time. In addition, GPS and RFID systems can allow users to keep track of locations of equipment and materials from shipment through erection.

This situation makes information about the status of various site operation and construction activities from the jobsite available to all of process units who need the information in real time.

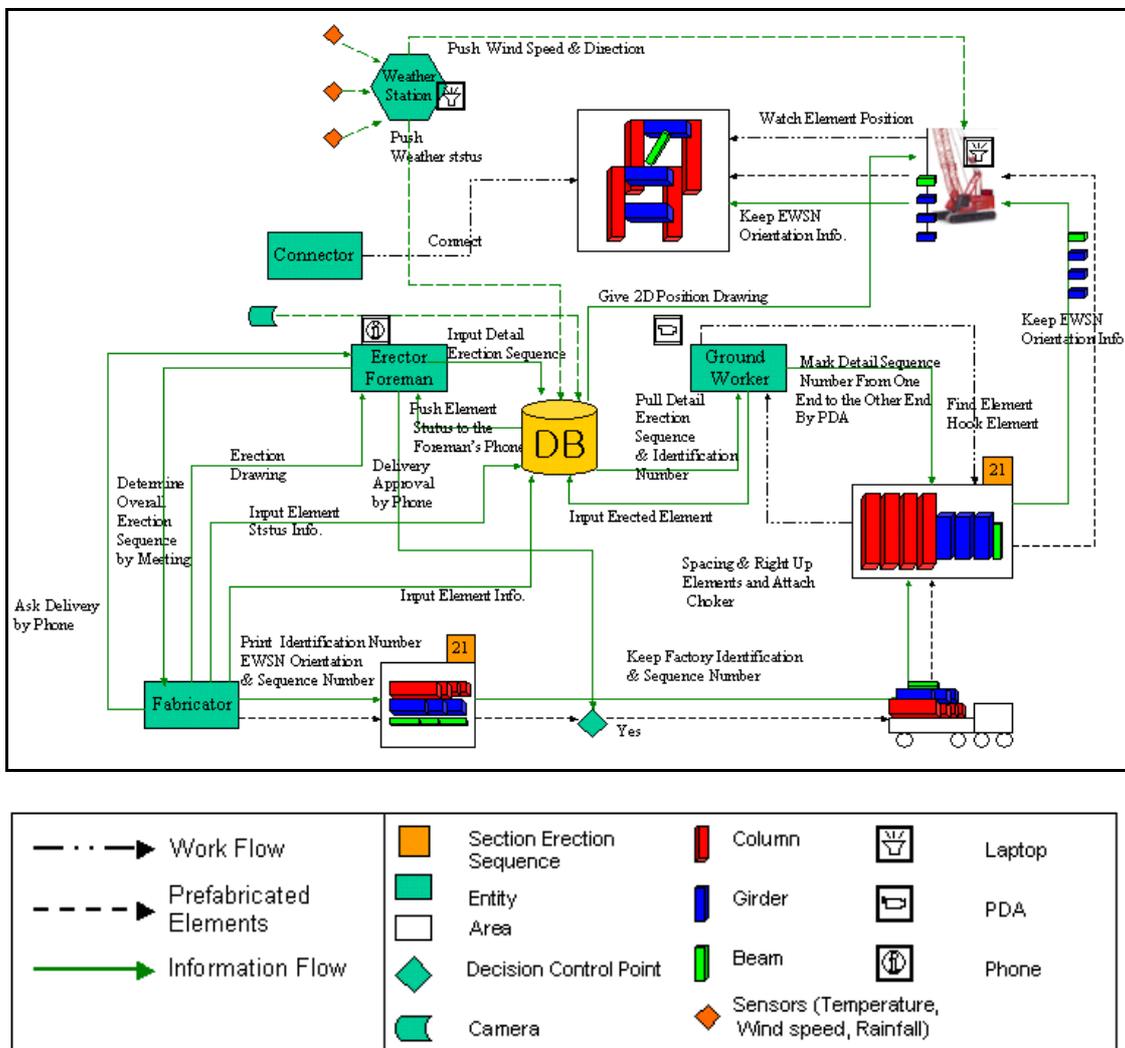


Figure 6.1 To-Be Data Flow Diagram

6.2 Construction of A Data Dictionary

While the Data Flow Diagrams (DFDs) mentioned in the previous section provides an overview of the major functional components of structural steel erection, they do not provide any detail about these components. As shown in Appendix F, the data dictionary (DD) specifies the name, definition, and other necessary attributes of each data element subjected to standardized data exchange. When data exchange between disparate applications are required, all data for exchange within both applications are translated into specified neutral data format (i.e., standardized terms, definitions, and format of data attributes) based on the data dictionary.

This data dictionary was limited to the following four major aspects of structural steel erection process: 1) tracking status for each pre-engineered building element, 2) locating and identifying to mark an erection sequence number on each engineered steel element at the laydown area, 3) positioning each engineered steel element at the final position area, and 4) acquiring real time weather information for safe crane operation.

6.3 Construction of An Application Schema

Application schema was developed categorizing the shared data extracted from the data dictionary. It defines a relation between data exchanged or data hierarchy. For the purpose of data exchange between disparate applications, standardization in the application schema is needed. When data exchange between different applications is needed, all data for exchange within both applications are converted into the neutral

application schema. Figure 6.2, with Appendix G, describes the proposed application schema for the steel construction process as expressed as a UML class diagram.

UML (Unified Modeling Language, see ISO/IEC 19501-1) is a popular formal standard language for describing processes which provide not only a graphical notation for declaring and using classes, but also a textual notation for referencing classes. The top compartment represents the class name; the middle compartment represents a list of attributes; the bottom compartment represents a list of methods.

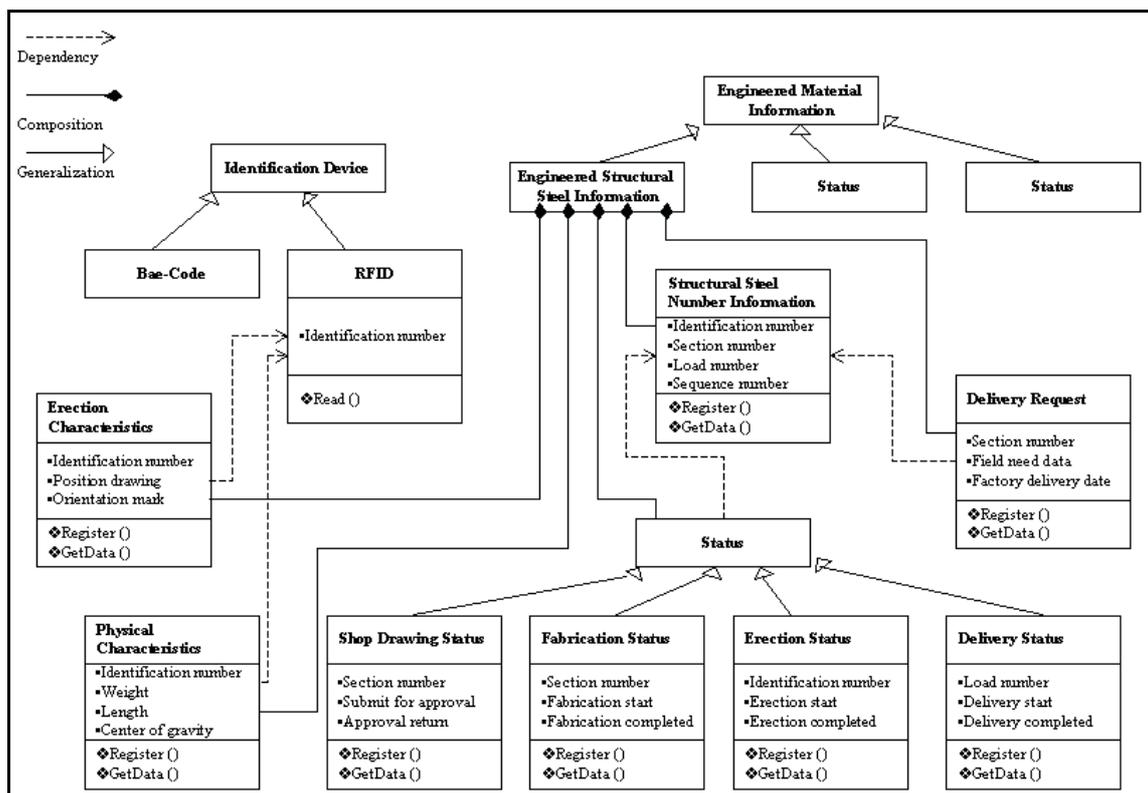


Figure 6.2 Class Diagram by UML Notation

In addition to the data dictionary and the application schema, a UML activity diagram was developed to describe how the steel erection process could be configured dynamically in response to external or internal events as shown in Figure 6.3.

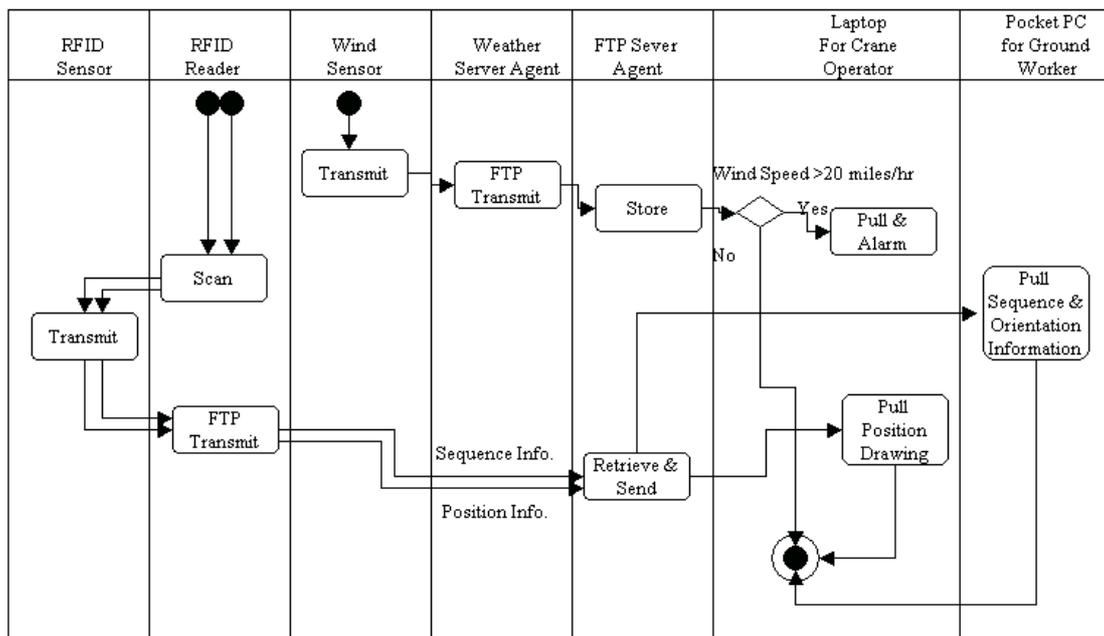


Figure 6.3 UML Activity Diagram

In our model of a steel erection process, the steel erection activity is modeled as an action and information flow as action flow. When a flow takes place, it can produce an event, letting the recipients take immediate action on it, and can produce another flow if the matching conditions are fulfilled. For example, when wind speed from remote sensors is more than 20 miles per hour, information flow “wind speed” alarm is triggered. Likewise, when a steel component’s identity is scanned directly by a portable RFID reader, relevant information such as size, weight, serial number, numbers of sections and

storage area, etc. is extracted from the common database through Wi-Fi networks in real time.

7. DESIGN AND DEVELOPMENT OF WI-FI AGENT SYSTEM FOR STEEL CONSTRUCTION

As already indicated in the previous chapter, a significant number of problems were identified resulting from inaccurate data transfers as well as from delays and interruptions in information flow, thus leading to a wasteful operation, errors, and even accidents. In this situation, a new approach needs to be developed to not only ensure precise control of information in a timely manner, but also increase level of communication between the multiple process units for structural steel construction.

The principal purpose of this chapter is to design Wi-Fi agent network to allow real-time communication, monitoring, and control of critical resources. First, Concept of Information Agent-Mediated Communication (IAMC) and the framework of Wi-Fi Agent Network are presented. Based on this concept and framework, Wi-Fi agent system is designed and developed.

7.1 The Concept of Information Agent-Mediated Communication (IAMC)

In Figure 7.1, the concept of Information Agent-Mediated Communication (IAMC) is developed to model a way of automatically capturing and distributing information regarding the state of a variety of construction activities through the use of Wi-Fi networks.

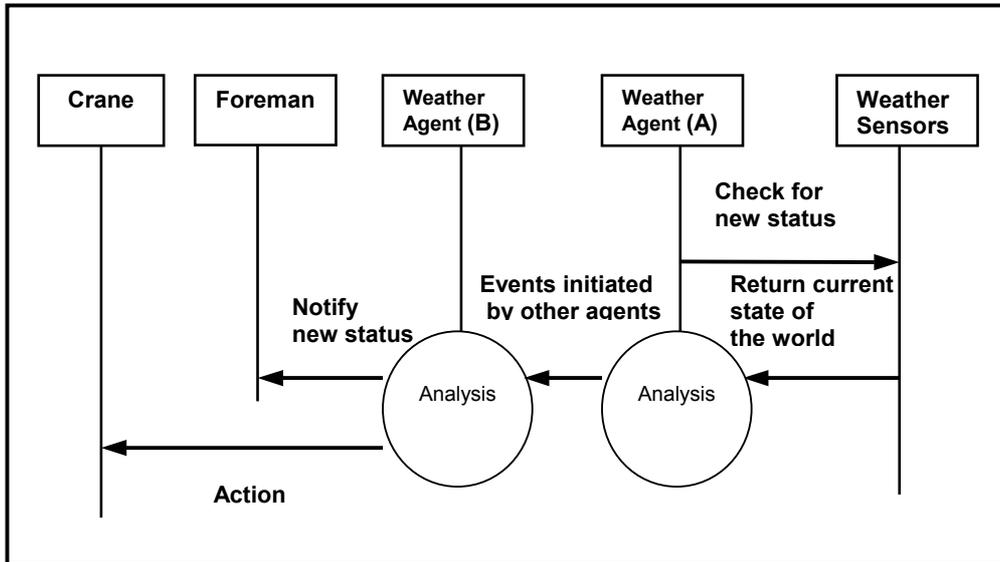


Figure 7.1 Conceptual Diagram of Information Agent Communication

In this concept, software agents are located in distributed networks and the agent obtains sensory input from its environment based on a prescribed schedule and can conduct preset actions in a flexible and timely fashion without the direct intervention of humans to feedback to the needs of information identified.

By proactively notifying the human and/or machine with the right information at the right time, agents can conduct autonomous routine tasks or even analyze received data to determine potentially critical situations in advance. The agents can supervise the status and notified changed conditions to the human and /or machine just in time when something of interest happens.

The proposed IAMC can also process information about weather conditions, equipment location, quantities of components, and the status of construction delivery activities on a real time basis.

7.2 Wi-Fi Agent Overall Network Model

In this research, the Wi-Fi agent network will be referring to an 802.11b wireless network into which hardware, software, or all kinds of process units can be plugged. The components for this Wi-Fi network include hardware (i.e., routers, repeaters, antennas, a solar battery and back-end fiber optic networks) and the system's built-in software for providing specific tasks and services (i.e., weather stations, a network camera server, and a project Web server). Figure 7.2 presents the framework of proposed Wi-Fi agent overall network.

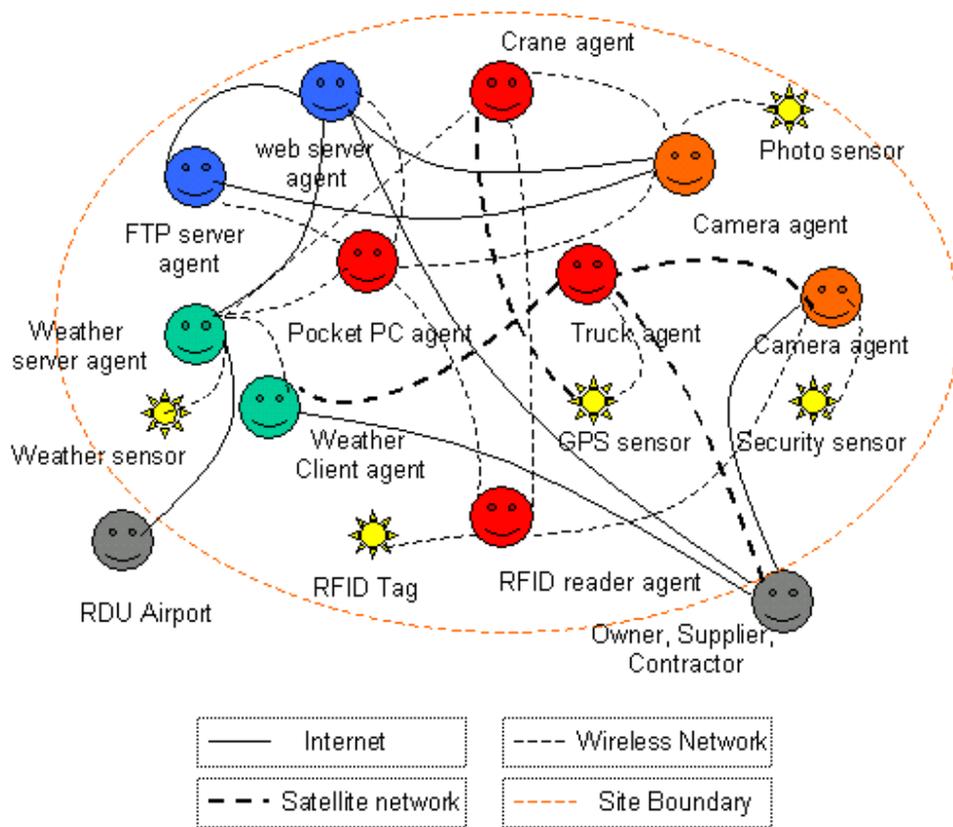


Figure 7.2 Wi-Fi Agent Overall Network Model

The Wi-Fi agent network is a proposed construct that is intended to enable the rapid formation and deployment of agent applications by combining agent technology with 802.11b wireless networks. The Wi-Fi agent network allows humans and agents to connect anytime from anywhere and get the information and capability they need. The Wi-Fi agent network is intended to facilitate the interaction between process units and serves as a tool that streamlines the flow of information and allows people and/or machines to communicate with each other in real-time. This Wi-Fi agent network covers the entire work site and allows any network devices such as network cameras, water

detectors, humidity and temperature monitoring devices, or even construction equipment such as cranes and forklifts to communicate to each other directly whenever and from wherever they want.

For example, a crane working on a jobsite can be equipped with sensors and interface devices with a wireless transmitter. These devices can issue a routine report to supervisors if the operator was mishandling the machinery, or operators can be warned via a wireless network when wind speeds are reaching a dangerous level. Through the Wi-Fi agent network, video images, environmental condition measurements at multiple locations, radio-frequency identification (RFID) tag data, and equipment status can be shared in real time. It also allows real-time processing of certain project information such as the status of drawing, Change Order, and RFI (request for information), including progress of works and site conditions.

7.3 Design and Development of Wi-Fi Agent System

In order to determine the real world applicability of applying the Information Agent-Mediated Communication (IAMC) concept to the case project, Wi-Fi agent system is designed in this chapter. In Figure 7.3, the architecture of Wi-Fi Agent System is sketched out, illustrating its basic functionalities. Detailed installation information on the various parts of the system will be explained in the subsequent chapter.

The main system is the Wi-Fi network that transmits and receives data with radio instead of wires and covers the entire construction site. This Wi-Fi network functions as an information highway to link various information agents, in this case a weather server

agent, on/off site weather client, Web and FTP server, and several network camera to provide real-time sensing, analyzing, alerting, and dissemination of weather and visual information regarding the steel construction site.

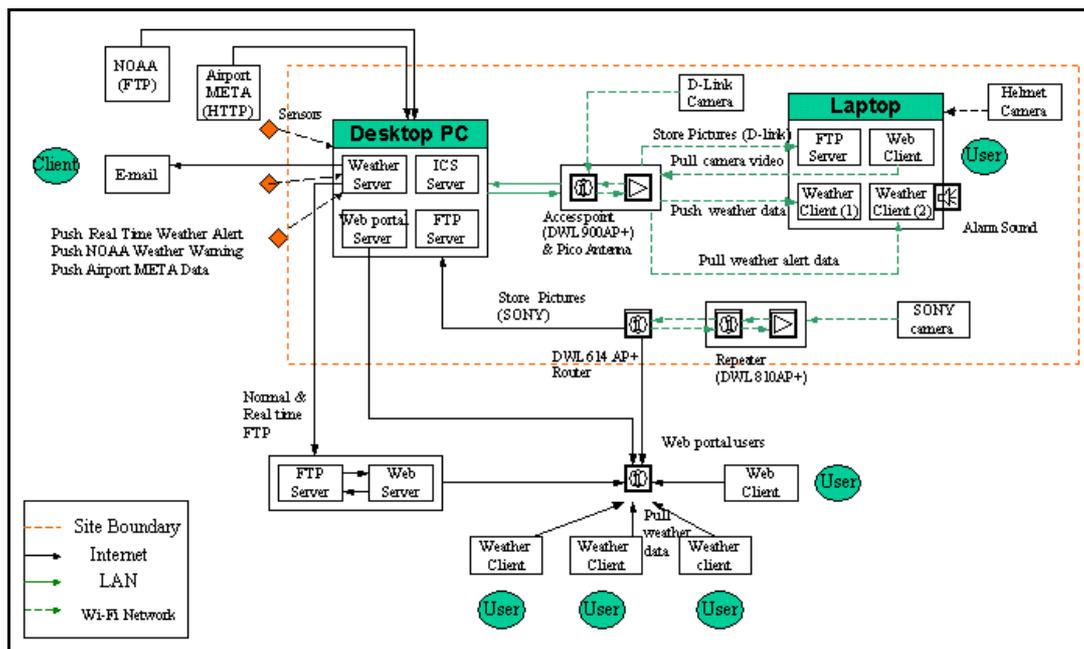


Figure 7.3 The Architecture of Wi-Fi Agent System

The D-link DI 614+ router typically functions as an access point that transports data between wireless devices and serves as a wireless device that bridges a wired network connection and a radio. The D-link DWL 810AP+ repeater is used in wireless networks to extend the range of the DI 614+ router's signals in a desired direction. The repeater receives all signals from the router and retransmits them to the SONY network camera and other wireless clients(e.g., pocket PCs) around the jobsite. The wireless SONY network camera provides real-time visual access to project participants from

anywhere in the world via Wi-Fi network. This SONY network camera is different from typical digital cameras and PC cameras because it has a built-in Web server and advanced zoom function.

The D-link DWL 900 AP+ access point acts as a central point between two or more wireless devices in an infrastructure network mode. A wireless client must transmit data to this access point, which then relays it to another wire or wireless device to which the data is addressed. The Pico antenna attached to the DWL 900 AP+ access point transmits or receives signals only in a narrow angle toward the laydown area at the jobsite.

The four wireless weather sensors include a rainfall gauge, a wind speed/direction, an indoor temperature/humidity/pressure transmitter, and an outdoor temperature/humidity transmitter. All the data from the remote sensors are wirelessly transmitted to the battery-powered PC interface connected to the weather server PC. The wireless PC interface, acting as a data logger, receives and stores all weather information from the remote weather sensors for at least two weeks.

The weather server PC runs a project Website that serves as a starting point for project participants to access several network cameras, weather information, and Web-based applications. These Web-based applications consist of four core modules. First, the camera module provides the ability for project participants to have real-time visual access to the jobsite almost anywhere in the world that has access to the Internet. Second, the communication module allows project participants to write, transfer, and retrieve messages back and forth among them while keeping a running log of all information.

Another module is the information sharing which allows the construction workers to upload and download different kind of electronic documents and information and retrieves the accumulated electronic data. Even though not implemented, the supply optimization module was developed to allow suppliers and contractors to plan material production and delivery and then synchronize delivery information through the Internet.

The Microsoft Internet Connection Sharing (ICS) server is also run on the weather server PC for any wireless device on the local network to access the Internet. It functions as the only gateway to the Internet. Any wireless device around the jobsite can communicate with another through the DWL 900 AP+ access point and reach the Internet through the ICS server.

The server's alert agent calls in data from the PC interface, stores data in the computer, and transfers all weather data to the NC State Web server through the NC State's FTP host. The off-site client's alert agents have the task of continuously pulling real time information from the NC State Web sever through a HTTP protocol, providing real time weather information to every remote project participant with Internet access.

On the other hand, the on-site client's alert agent is also responsible for pulling real time information from the same Web server via an 802.11b wireless connection, monitoring weather status (i.e., wind speed and wind direction) in real time, and alerting a crane operator at any time when reaching to the threshold point set by users. Currently, there is no rule set by OSHA concerning wind in crane operation. It is up to the crane operator to determine when wind speed becomes unsafe. If unattended, dangerous wind speed often leads to enormous loss of life and property.

A multi-media augmentation system was developed to allow real-time interaction and to visualize a problem through a helmet wireless camera mounted on a worker's helmet or a mobile wireless camera carried by the foreman. The system consists of a mobile wireless network camera, a wireless Laptop computer running Windows 2000, and a mobile wireless helmet camera, being supported by Yahoo voice messenger function to enable real-time two-way voice communication. One camera provides the overall view and the other detail view for the expert at the designer office to see the worker's field of view. The foreman equips a D-link camera, microphones and a Laptop connected to the wireless LAN to point to the object being discussed with the remote expert. The camera with microphones was mounted on the worker's helmet to captures close view images of the same object.

8. INSTALLATION AND TESTING OF WI-FI AGENT SYSTEM

In this chapter, Wi-Fi agent system was set up and deployed to test its functionality and feasibility which will be detailed in the subsequent chapter. Considerations about how to better install and set up wireless devices are discussed.

First, FCC and the University's wireless policies are reviewed to avoid any interference problem. Security problems for the proposed wireless LAN are also discussed.

8.1 Descriptions of the Cates Project

The new Cates Plant is located on the North Carolina State University campus in Raleigh, North Carolina and is bounded by Cates avenue, Dan Allen Drive, Morill Drive, and Miller Intramural Fields. The Chilled Water Plant occupies a building area of about 6,250 square feet. This project consists of a new 4,000 ton central chilled water plant adjacent to the existing Cates Plant. The general contractor is Gilbane Building Company and the steel supplier is Dave steel company.

Due to its location, the existing Cates Plant and Carmichael Gymnasium on the NC State campus provided perfect conditions for deploying wireless devices. The Activity Building, the annexed building of the Carmichael Gymnasium, did not have a high-speed Internet connection point and power sources were not available near proposed positions for wireless equipment.

On the other hand, the existing plant had no problem providing high-speed Internet access and power sources. However there seems to be a lot of RF interference resulting from noises generating from rotating equipment such as fans, boilers, cooling towers, and pumps in the existing Cates Plant.

8.2 Wireless Policies, Rules, and Regulations (NCSU & FCC)

According to the Cisco reference guide for Aironet antennas and accessories (2005), the Industrial, Scientific, and Medical (ISM) bands of radio frequencies typically allow users to operate wireless products without requiring any special permissions, but this regulation is different depending on countries. In the U.S., there is no requirement for FCC licenses, but the FCC (the Federal Communications Commission) restricts transmitter output power and maximum antenna gain to maintain multiple wireless networks with minimum interference with one another.

In point-to-multipoint systems, the FCC has forced an upper limit on the EIRP (effective isotropic radiated power) to 36 dBm where EIRP is equal to TX power plus antenna gain. The antenna gain is increased by 1 dB for every dB that the transmitter power is decreased. Our 2.4 GHz repeater transmitter power is 17 dBm, which is 15 dBm lower than maximum. This then allows the maximum antenna gain up to 19 dBi.

In point-to-point systems for 2.4 GHz systems using directional antennas, the antenna gain is increased from the initial 6dBi, by 3 dB for every dB the transmitter is decreased below 30 dBm. Because our transmitter power is 17 dBm, which is 13 dB below the 30 dBm level, antenna gain can be increased by 39 dB (45dBi).

In addition to FCC regulations, Wi-Fi network must comply with local regulations, because the FCC does not regulate how this ISM band is used in local areas (in this case, North Carolina State University campus). Therefore, the private wireless networks on campus must be set up in compliance with University policies and procedures not to interfere with the NC State public wireless network.

8.3 Wireless Security Considerations

Unlike wired networks, wireless networks use radio signals to communicate. Because of radio signal traveling outside a network, other wireless devices can pick up unprotected signals and either connect to the network or capture information being sent across it. IP or MAC Filters can be used to prevent hackers from accessing our wireless LAN through the Access Point. For the proposed Wi-Fi network, the DI 614+ was set up to deny Internet access to wireless clients using the assigned MAC addresses for the wireless adapters.

For added security on the network, the DI 614+ built-in firewall was also configured to prevent traffic from passing through the device. The DI 614+ firewall feature filters out unrecognized packets to protect our wireless LAN network against malicious hackers so all computers networked with the DI 614+ can be protected from the outside world. It works in the same way as IP Filters with additional settings. However, the DI 614+ MAC Address filtering rules have priority over the Firewall Rules.

Those who implement private wireless networks may employ wireless encryption technology if needed. However, current wireless encryption technologies are weak, and it

is possible to passively eavesdrop on wireless network traffic, resulting only in overhead to the wireless network, so it was not used in our network.

8.4 Installation of Wireless Backbone Networks

With the skills and knowledge obtained in preliminary work, following two backbone networks were installed around the experimental facility.

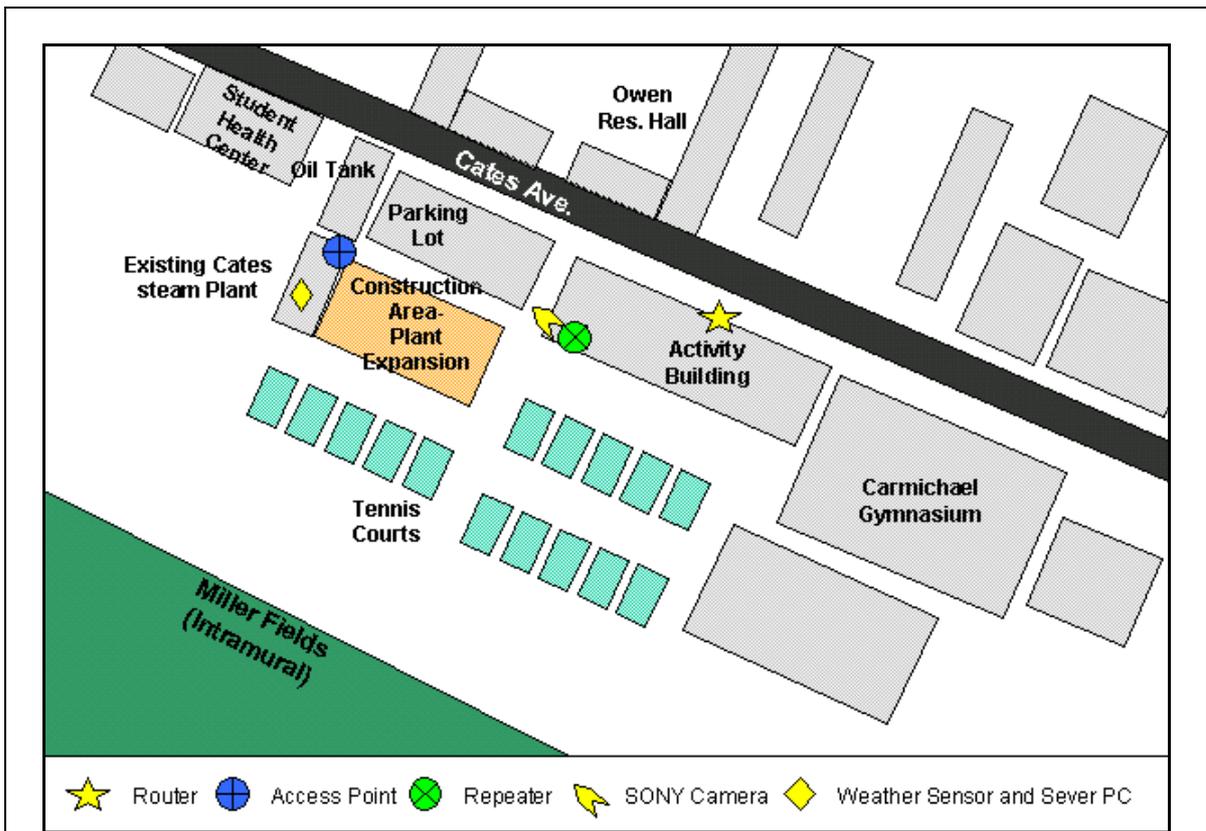
8.4.1 First Backbone Network in Carmichael Gymnasium

As shown in Figure 8.1, the DI 614+ wireless router was installed in the communication room in the second floor of the Activity Building and connected to the Internet connection point via Internet cable. The DWL 810AP+ wireless repeater was installed at the middle point close to the far corner of the climbing wall in the Activity Building to relay the router's wireless signal to the multiple wireless clients such as Pocket PC s, wireless laptops, mobile cameras, and the SONY camera.

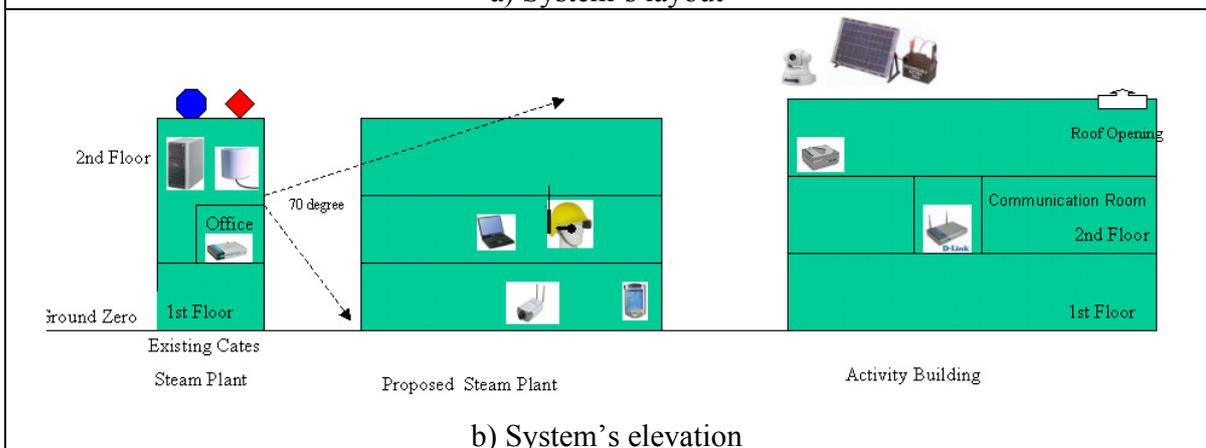
The DI 614+ can be configured as a virtual server so that remote users can access the SONY network camera via the router whose IP public address was 152.1.201.21. The SSID of wireless devices connected to the router was set to CARL and the channel set to six. Encryption and DHCP (Dynamic Host Control Protocol) server were disabled and Infrastructure Mode was selected.

By default, the DWL 810+ was set to repeating mode, inputting the MAC address of the remote router to repeat its signal. The repeater is positioned at the best reception

point after conducting a site survey. An indoor 2.5 dBi diversity antenna was attached to the DWL 900AP+ repeater.



a) System's layout



b) System's elevation

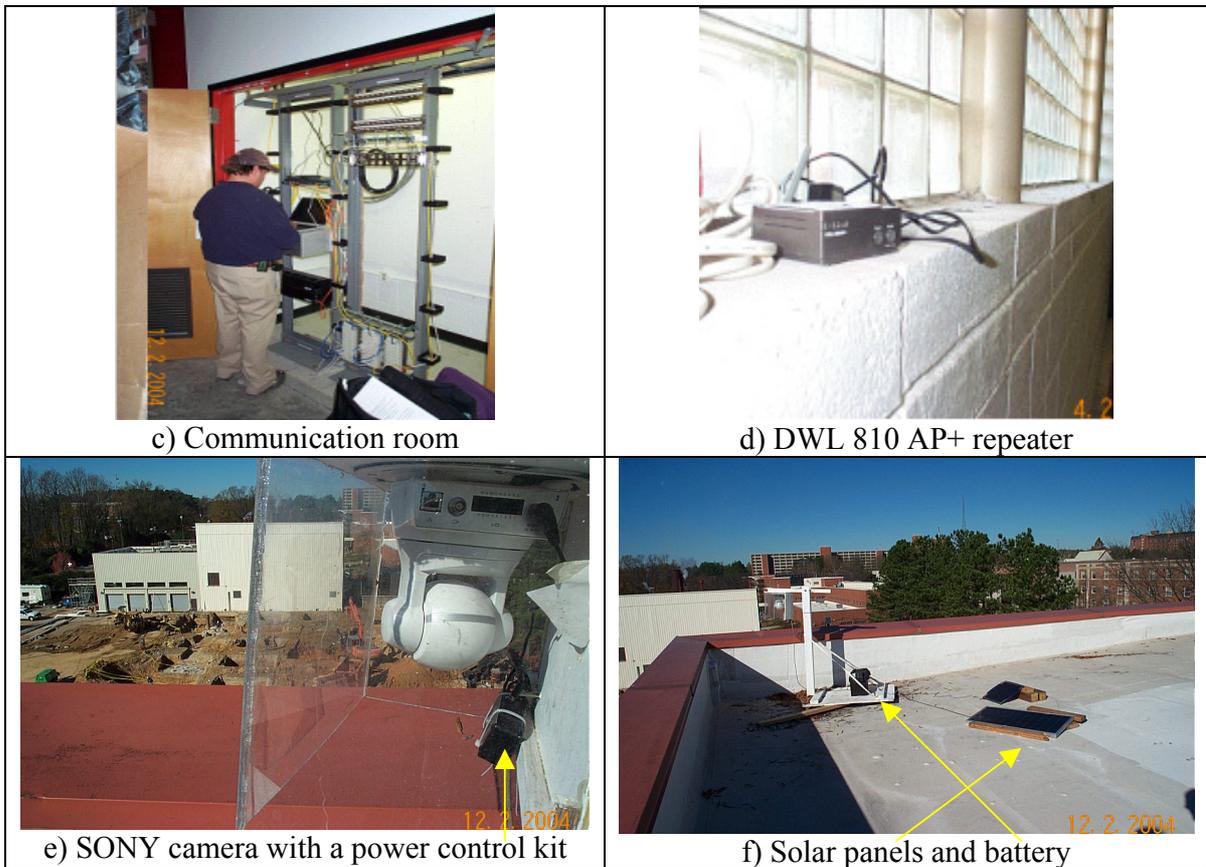


Figure 8.1 Wi-Fi Agent System Installations

8.4.2 Second Backbone Network in the Existing Cates Plant

The backbone network installed in the Activity Building did not provide enough wireless coverage in the laydown area. As another way to provide better coverage, the ICS server computer which redirects Internet traffic to the devices on the LAN was installed on the roof the main office of the existing Cates Plant. ICS server was hooked up to the Internet connection point inside the main office and assigned the public IP address 152.1.93.162. Two network adapters were installed inside the computer. One

network adapter went to the Internet and the other went to the DWL 900 access point which was mounted near an inside wall in the spare parts room of the same plant via wire. The desktop PC was always turned on and used as the ICS server. Any wireless device on the wireless local network could access the Internet through the DWL 900 AP+ access point which creates a Wi-Fi network that covers the construction site.

An 8.5dBi Pico antenna (D-link ANT24-0801) was attached to the DWL 900 AP+ to provide a better coverage pattern that uniformly directed the radio energy against the wall. This directional antenna provides a relatively wide beam pattern having 70° both horizontal and vertical coverage. The DWL 900 AP+ antenna's transmission power ranges from 10dBm (weak) to 17dBm (strong). The antenna transmit power was set to 17 dBm to maximize coverage. The DWL 900 AP+ SSID was set "CATES" to avoid any interference with aforementioned DI 614+ wireless network.

8.5 Installation of Alert Agent System in the Existing Cates Plant

The weather server was installed in the same computer where the ICS server was set up. Figure 8.2 shows the components of the alert agent system. Wireless remote weather sensors were positioned on the roof of the Cates Plant. The wind and rainfall radio sensors were mounted to the top end of a steel mast fixed on the roof and these remote sensors were solar-powered with lithium battery backup included. This battery makes up for periods of long darkness and weak sunlight caused by bad weather. The battery is then recharged during periods of light.

The solar cell in the sensor housing was accurately aligned to face south to set the reference point for measuring the wind speed and direction and then was positioned in an exposed area to let the wind to be able to approach the sensor from all sides. It was assembled vertically in the retaining mast in order to ensure accurate measurements.

The rainfall transmitter was installed approximately 3 ft above ground level to protect the solar cells from dirt. Those sensors were wirelessly connected to the PC interface attached to the weather server agent PC's serial port (9-pin).

The weather server agent PC was set to receive the weather data from sensors, analyze the data, create Web data files, and ftp-upload the files into NC State's Web server directory via NC state's FTP host every 3 seconds, thus creating an automatic weather Web page with updates.

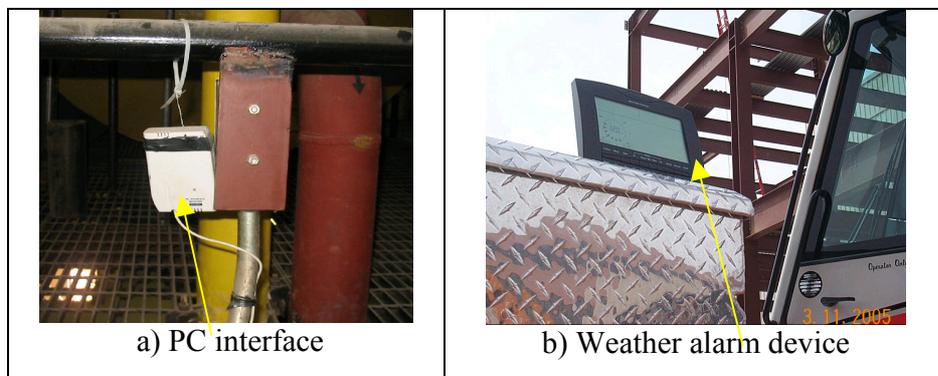


Figure 8.2 Components of Alert Agent system

The laptop for a crane operator was installed inside the crane cabin to observe how an alarm works. The client's alert agent mounted on a mobile wireless laptop was set to

program multiple alarms for various weather conditions. In this case, it was set to warn the crane operator by triggering an automatic sound alert and e-mail whenever a wind speed exceeds 20 miles per hour. The laptop was connected to Internet to pull an alarm data from the Web server via local Wi-Fi wireless network deployed to cover the entire jobsite.

As another alarm device, the weather alarm device (Figure 8.2 b) was also installed inside the same cabin to check its functionality. Unlike the laptop, this station alarm device directly communicated with the weather sensors installed in the roof of the existing Cates Plant via a 433 MHz wireless network.

8.6 Indoor Test and Installation of the SONY Camera

The power source for the SONY camera was acquired from a battery with solar power chargers because there are no available power sources in the adjacent area on the roof of the Carmichael building. Before installation, the SONY camera was hooked up to a meter and tested it to see how much power it actually consumed. It was found that the camera sitting still used 0.88 Amps, and used 1 A while moving. This translates to roughly 10.6 Watts constantly being consumed. Based on this estimate, 18-Watt solar cells (one 6 Watt panel and one 12 Watt panel) were used to supply the required power to the camera. A car battery, charge controller, and power control kit were added to the system as shown in Figure 8.3.

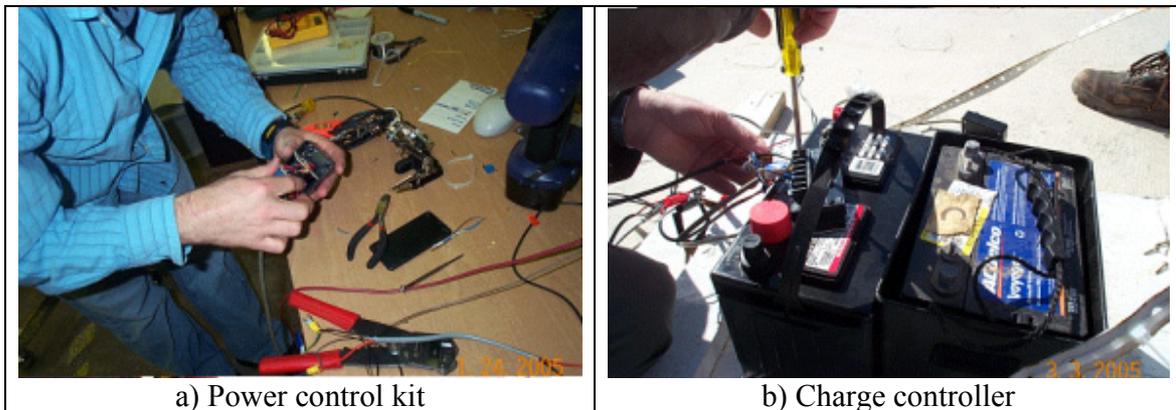


Figure 8.3 Solar Power System for SONY Wireless Camera

A charge controller prevented the solar panel from overcharging the battery. The solar panels were connected to the battery. As sun shines on the solar panel, the circuit passes charging current to the battery. During periods of darkness or bad weather with little or no sunlight, power is provided to the sensor by a backup battery. The camera received its power from the batteries instead of directly from the output of a solar panel.

The power control kit contains a low voltage load disconnect circuit. The camera power turned on only when the solar panel input exceeded 12V. As long as the battery voltage was above 12V, the camera power was switched on. When the battery voltage dropped to the 12V, the circuit turned camera load off. It also had a photo sensor circuit so that at night the camera shut down.

After an indoor test, panels were arranged in parallel and mounted on the roof of the Activity Building. The SONY camera was set up to capture and upload pictures to the project FTP server, which runs on the weather server PC.

8.7 Installation of Other Camera Systems

Two additional network cameras were used. The D-link mobile wireless network camera for a multi-media augmentation system was set up to automatically capture a worker's view and transfer it to a wireless Laptop's FTP server every minute through the DWL 900 AP+ access point anywhere within its wireless coverage area while at inspection. Private IP addresses were assigned, 192.168.0.4, and 192.168.0.6 respectively. The camera's video resolution was set to 640x480, the frame rate was set on Auto to obtain an optimized data transmission rate fitting for our wireless network condition, and video compression rates were set to Medium to generate medium file sizes with moderately good video quality. The power of those devices was supplied from a portable 12 V car battery. One wired network camera, Netcam, was put inside the Cates Plant to provide an overall view of the construction site. This camera was connected to a separate Internet access point in the building; therefore, it served as an external link to the system.

8.8 Assessment of Environmental Effects on the Wi-Fi Signal

Even though Wi-Fi networks have been proven to work well in a typical finished building, there are very few cases in which the technology has been tested at a plant construction site under the presence of construction machines and equipment that can cause interference with a signal. The objective of this section is to verify whether the proposed Wi-Fi network provides an acceptable data transfer rate when implemented in a

construction site environment where a variety of construction machines and equipment are operated.

8.8.1 Wireless Site Survey Plan

The material and density of components used in a plant construction have a significant effect on signal penetration. In outdoor environments, many objects can have an effect on propagation patterns, such as trees, vehicles, and buildings.

Due to these kinds of reasons, it is still very difficult to identify the number and location of associated repeaters, data rate, signal strength, and signal quality at the laydown area without an RF site survey. Thus, the RF site survey was performed to check wireless coverage while installing wireless network devices. The D-link site survey software was employed to measure signal strength and signal quality at each designated location. The D-link site survey software provides link information on the connection state, SSID, connection speed and channel number, as well as link quality and signal strength. As well, it provides a graphical profile of the link quality and signal strength over time.

The signal strength is measured in a dB scale of the actual signal, which defines how strong the signal is. The link quality determines the signal to RF background noise levels which define how clear the signal is. Lower link quality level means higher packet loss during transmission. Professional analysis tools (i.e., protocol analyzers, RF analyzers, and simulation tools) to identify details of performance problems and

characterize the source of RF interference were not used because these tools go beyond the scope of this research.

The field signal measurement was performed in three situations to test first hypotheses established in section 1.5. In the first situation, the signal is measured from the DI 614+ router in the communication room in the second floor of Activity Building. A 2.5 dBi diversity indoor antenna was attached to the router. The Activity Building director did not allow researchers to put a high gain antenna inside the building due to the possibilities of interference with their wireless devices. As another way to extend the radio range without repeater intervention, an outdoor antenna was tried to be installed on the roof of the building, but there was no opening or hole to pull an outdoor antenna cable through the building walls/roof.

Thus, the second situation was developed to add a repeater on a wall in the one corner of the Activity Building (along the communication path between the router and the target receiver) to repeat the router's signal. A same 2.5 dBi diversity indoor antenna was also attached to the repeater.

For the third situation, a 900AP+ access point was set up in the center of the 2nd floor of the two-story Cates Plant to provide better coverage in the laydown area.

In each situation, the signal is measured at 7 points on the site as shown in Figure 8.4. The high and low points of signal strength and link quality within 1-minute time interval are recorded.

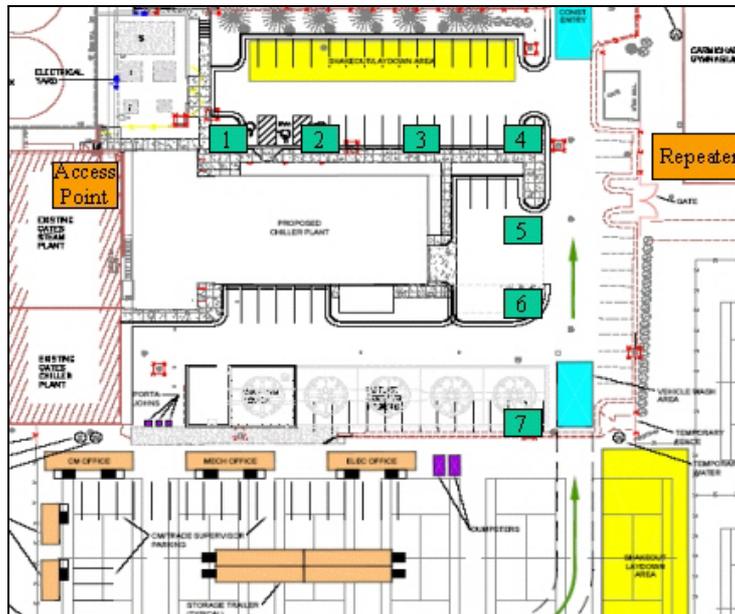


Figure 8.4 Measured Points of Wireless Signal on the Site

8.8.2 Acceptable Data Throughputs

In the 802.11 standard, a maximum transfer speed is dynamically picked up depending on link quality between the client device and the access point. This standard allows the wireless client and access point to pick up the best value from a fixed set of speeds such as 1, 2, 5.5, and 11Mbps data rates. As the link quality deteriorates, the access point automatically slows the data transmission rate down to lower data rates in an attempt to continuously maintain a connection.

To determine an acceptable data rate from the three wireless cameras, the throughputs of actual data were measured at a specified indoor condition as attached in Appendix B. A survey graph was drawn out of the collected data as shown in Figure 8.5. The X-axis of the graph represents a count of the observation taken while collecting the

data. The Y-axis represents the data throughput in Kbps. The transmission rate from three cameras (SONY, Panasonic, and D-link) are plotted to see how they are compared.

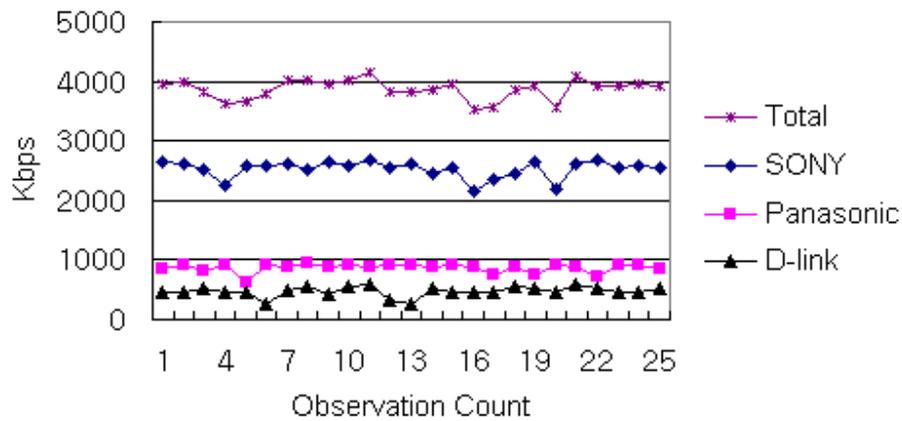


Figure 8.5 Data Throughputs Measured from Three Cameras

The data rate from three wireless cameras was measured to be about 4.1 Mbps. Considering the rate needed for other agent applications, the minimum acceptable data rate was determined to be 5 Mbps in our 802.11b network. In most implementations, adequate coverage means support of this minimum acceptable data rate.

8.8.3 Wireless Signal Measurements

In the first situation, the signal from the router was measured on the designated points. However, a wireless client, laptop could not be associated with the router. Power loss of an RF signal propagating through space depends on the distance and line of sight between the receiving and transmitting antennas. There exists a 6 inch thick concrete

climbing wall and two 4 inch brick walls toward the west of the Activity Building along the propagation path between the router and the laptop as shown in Figure 8.6.

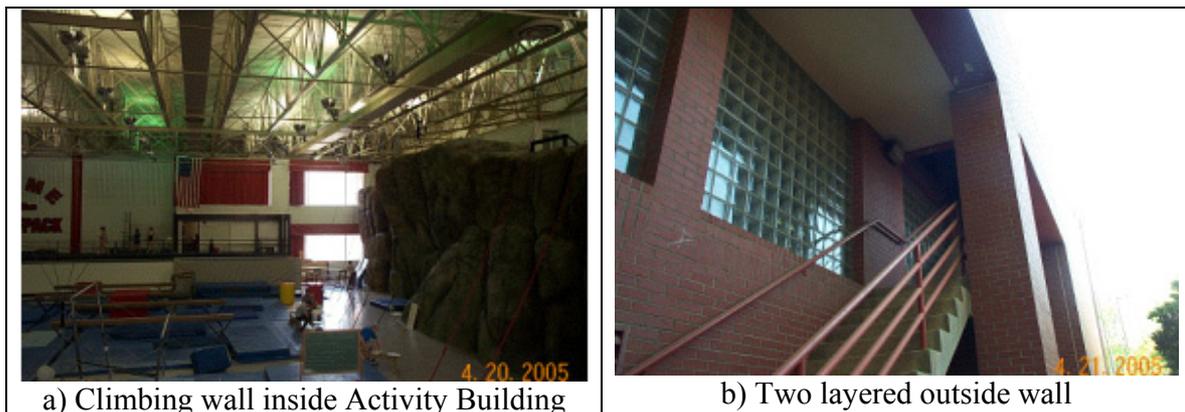


Figure 8.6 Building Conditions

This thick walls reflected signals, resulting in poor penetration. A solid metal door of the communication room where the router was installed was another obstacle which blocked radio transmissions.

The link budget was calculated through the whole transmission chain to theoretically explain loss of connectivity to the router. For a good wireless link, the transmitting power + Antenna Gain (transmitter) – Pass Loss A to B + Antenna Gain (receiver) must be greater than receiver sensitivity (Bijgewerkt, 2005). To achieve a very reliable link, a margin of at least 10 dB is needed to accommodate local fading (fluctuation in received power) and Fresnell effect. The radio wave is attenuated while propagating through space. This attenuation is calculated using the following formula: At

2.4 KHz, this formula is: $100+20 \times \text{Log R (Km)}$. R is the distance between the transmitting and receiving antennas. Typical office obstacles such as doors, windows, and walls have known levels of attenuation. These values of attenuation should add to the propagation loss mentioned earlier. According to Geier (2002), metal door in brick wall has the attenuation values of 12.4dB. SMA connector loss can be at a maximum 0.5 dB. Based our figures on a 17db transmitting power, 2.5dBi transmitter antenna at the one end, and 2.0 dBi receiver antenna at the other end, the link budget is:

Pass Loss A to B : $(100 + 20 \times \text{Log } 0.1) + 12.4 \times 2 + 0.5 \times 2 : 106 \text{ dB}$

Required Receiver Sensitivity : $17 + 2.5 + 2 - 106 : - 84.5 \text{ dB}$

Threshold Sensitivity : $-84.5 \text{ dB} + -10 \text{ dB (fade margin)} : -94.5 \text{ dB}$

Actual Receiver Sensitivity (@1Mbps) : -91 dB

From this calculation, there is a 3.5 dB difference between actual receiver sensitivity and the threshold sensitivity. In addition, interferences can occur from other radio sources (such as other WLAN networks, construction equipment, and rotating equipment inside the Cates Plant). Therefore, it is presumable that the link between the laptop and the router did not work.

In the second situation, the router's signal level was checked inside the building to determine a repeater's location in the range boundaries of router. The results of this testing indicate the location of repeaters. The repeater was placed indoors to extend the

router's signal at the nearest place to the laydown area where the router's signal strength was 41% ([low] ~ 47 % [high]) and link quality 88~96%.

To see if the repeater's signal could reach the laydown area, the repeater's signal was checked at the designated survey points outdoors. The measurement was done in the afternoon of typical working day with a fair sky. There was one bulldozer, three generators, one remi-con truck, and one forklift working on the site. There was one crew welding galvanized columns and two crews compacting the laydown area during the measurement as shown in Figure 8.7.



Figure 8.7 Construction Equipment on the Site

Appendix C shows data rates and signal readings at designated survey points. Three stretched survey graphs below were drawn out of the collected data. The X-axis of the graph represents a location of the survey points taken while collecting the survey data. The Y-axis represents the collected value of interest (i.e., link quality, signal strength,

and transmission rate) which are plotted along with the survey points to see how they are affected in terms of distance.

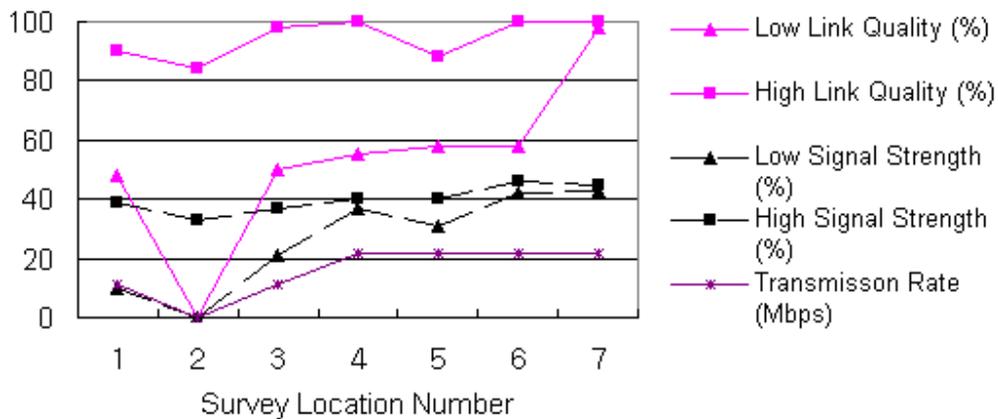


Figure 8.8 Signal Survey from Repeater (DWL 900AP+)

In Figure 8.8, the signal around the laydown area did not appear as strong as desired. It is confirmed that the big variance in link quality results in lower data throughput, causing the data speed to drop down to below 11Mbps at the location between the point number 1 and 3. This variance in link quality reading likely indicates that RF interference is affecting the wireless LAN. Actually, the point 2 and point 7 were located same distance (about 240 ft) from the repeater. Nevertheless, the main reason to loss of connectivity and reduction in radio signal strength at the point 2 is the fact that the large solid concrete climbing wall in the Activity Building blocks signal from directly passing through, thus causing multipath fading which occurs when a transmitted signal takes more than one path to a receiver and some of the signals arrive out of phase. It is

apparent that the multi-path problem would introduce high bit error rate, which meant a big variance in link quality despite relatively strong signal strength.

According to the indoor experiment, the acceptable transmission rate should be over 5 Mbps to enable camera operations and other related agent applications, thus the wireless coverage in the laydown area located between point 1 and 4 was not satisfied.

In the third situation, the measurement was performed on two different days, one on a working day, the other on a non-working day to identify the effect of radio interference on working construction equipment.

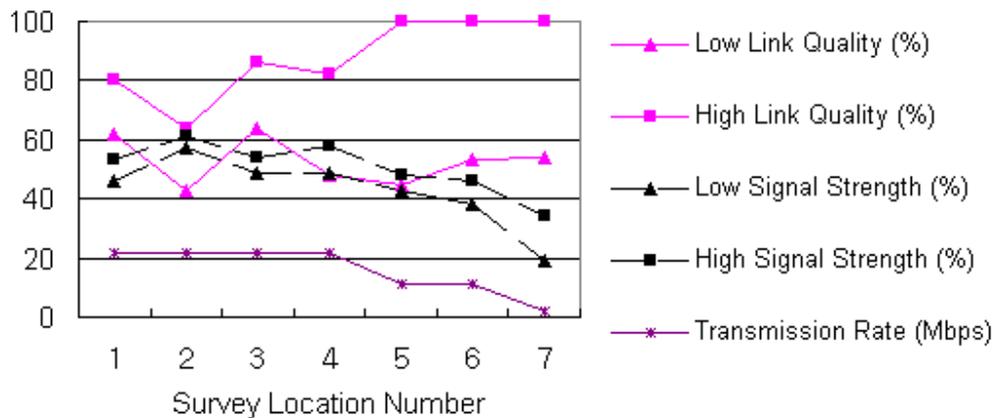


Figure 8.9 Signal Survey from Access Point (DWL 810AP+) on Working Day

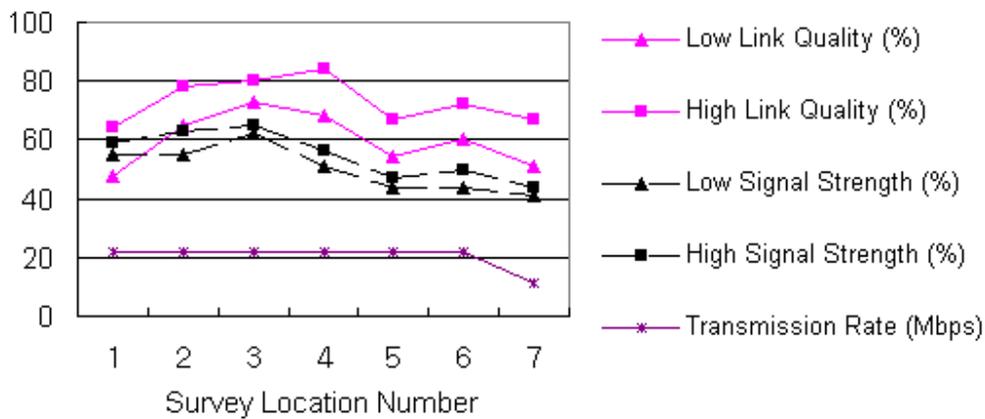


Figure 8.10 Signal Survey from Access Point (DWL 810AP+) on Holiday

Comparing the both Figures 8.9 and 8.10, the variance in link quality on the working day is far higher than that of the non-working day. This resulted in the connection speed dropping to a lower rate beyond point 4 on the working day. The most significant conclusion from this testing is the fact that there is interference arising from the construction equipment. Nevertheless, much of the area including the laydown area was covered, except point 7.

Another interesting point is that there is no big difference in signal strength in both situations. This implies that the variance in link quality is considered a dominant factor in establishing transmission rate.

The signal degradation pattern between point 1 and 7 is non-linear. Another important finding in Figure 8.10 is the fact that the variance in link quality is independent of those in signal strength. The signal strength for the third situation was strong enough to maintain continuous associations as compared to the second situation. The reason for

this is because the access point was located against a thin insulated metal wall with small opening inside the Cates Plant with the directional antenna facing the laydown area.

In summary, from the results above, it is concluded that the 802.11b Wi-Fi network works on the construction site full of machinery, but connectivity is affected by construction equipment's noise level and different site conditions degrading the performance of the wireless LAN. In addition, these findings provide two important evidences.

First, 802.11b experienced significant fluctuation in link quality when RF interference is present. The presence of RF interference caused lower data throughput.

Second, when wireless components were not placed in direct line of sight to one another, it made signal levels fluctuate. This is caused by multipath fading of radio signals between a transmitter and a receiver.

9. ON-SITE DATA COLLECTION AND ANALYSIS

In the previous chapter 7 and 8, Wi-Fi agent network system was designed, implemented, and tested to the case project to allow seamless and fluid communication of process units anytime without human intervention.

The main focus of this chapter is to assess the functionality, feasibility, and associated effects on Wi-Fi Agent system, which provides real-time sensing, analyzing, alerting, and dissemination of weather and visual information of a construction site. For this purpose, comprehensive field data was collected and analyzed.

9.1 Interoperability Test of An Alert Agent Platform

The one major aspect which affects agent performance is the platform that the agent system runs on. The agent system can be mounted on platforms ranging from workstations to mobile devices like PDA. Inevitably, these systems would have different hardware configurations like processor, memory, and disk storage. They might run on various operating systems namely Window NT, Window 95, Unix, Window CE, and many others which might influence the agent performance.

In line with this, the weather agent software was mounted on the Hitachi Flora Prius note 220K Notebook with 64MB memory and run continuously in the Window 2000 professional operating system to see if the software matched the hardware. To receive signals from Lacrosse WS-2010 wireless sensors, the Lacrosse WS 2010-13 PC

interface was hooked to the Notebook through the Iogear USB232A USB to serial adapter because the Notebook computer is not equipped with a serial interface.

Upon examination, the weather agent software began to dump physical memory causing program crashes whenever running for several hours, displaying a error message about the USB driver (ser2pl.sys). Hence, the computer's hardware function was optimized at a maximum to solve "computer down" problems. The weather software company advised us to check for the possibility of a bad memory module. Therefore, the Memtest86 memory diagnostic program was used to detect a memory error. There were no errors reported by Memtest86 after 2 passes of test (2 hours of running).

Finally, the USB to the serial adapter's driver was checked to find any interoperability problem on this driver. Then the latest driver from the company was downloaded and reinstalled, but the computer still crashed. It has been acknowledged by several USB adapter' producer that incompatible USB drivers can cause operating problems. So, Iogear, the maker of our USB adapter, was contacted to check this problem.

The company noted that sometimes users came across a PC that has symptoms like this, and it often comes down to hardware interoperability problems. It turned out that the USB driver was not compatible with the Notebook computer because the weather agent software did not experience any more program crashes after the system was installed into a normal desktop PC running the same Windows 2000 program with the same capacity of 126 MB memory.

9.2 Alert Agent Performance

In order to ensure that the client's alert agent can communicate with the server's alert agent located in the Cates Plant, two tests were performed by using the ICS Internet connection mentioned in chapter 8. The difference between the two tests lies in the way data was routed.

In the first test, the weather client viewer was launched into the mobile Laptop to see how it worked at the crane set up area. The Lacrosse 2010-13 PC Interface was connected to the Weather server computer to collect wireless weather data from the remote sensors installed on the roof of the plant. The weather server pulled the received weather data from the PC interface to its computer and automatically uploaded the weather data to the Web server through its real time FTP upload function. Over the internet from the URL, the weather client viewer pulled the weather information and had it displayed on the client's computer screen at 3 second intervals via the Wi-Fi network and Internet. There seemed to be no delay in receiving the weather data from the server.

In the second test, another weather client's agent was installed on the same laptop to automatically transfer the data from the weather server to 1 or more weather clients over the wireless LAN every 1 minute. The weather data from the server agent was broadcast to the client agent in real time through the Wi-Fi Network. These broadcast data were received by the weather client agents and displayed on their screens. The default multicast IP address, 231.31.31.31 was used with the port number 333 to multi broadcast the data. Figure 9.1 shows the weather client viewer and the alert agent working on the laptop.



Figure 9.1 Alert Agent (Left) and Client Viewer (Right)

Another major aspect affecting agent performance is the network conditions. The speed of agent communication is highly dependent on the network conditions and an agent system's performance.

In order to determine network speed, as shown in Figure 9.2, a ping test was performed with the wireless Laptop at the crane setup area where wireless network coverage was satisfied.

```
C:\WINNT\system32\cmd.exe
(C) Copyright 1985-2000 Microsoft Corp.
C:\Documents and Settings\Administrator>ping 192.168.0.1
Pinging 192.168.0.1 with 32 bytes of data:
Reply from 192.168.0.1: bytes=32 time<10ms TTL=128
Reply from 192.168.0.1: bytes=32 time<10ms TTL=128
Reply from 192.168.0.1: bytes=32 time<10ms TTL=128
Reply from 192.168.0.1: bytes=32 time=10ms TTL=128
Ping statistics for 192.168.0.1:
    Packets: Sent = 4, Received = 4, Lost = 0 (0% loss),
    Approximate round trip times in milli-seconds:
        Minimum = 0ms, Maximum = 10ms, Average = 2ms
C:\Documents and Settings\Administrator>ping 192.168.0.50
Pinging 192.168.0.50 with 32 bytes of data:
Reply from 192.168.0.50: bytes=32 time<10ms TTL=127
Ping statistics for 192.168.0.50:
    Packets: Sent = 4, Received = 4, Lost = 0 (0% loss),
    Approximate round trip times in milli-seconds:
        Minimum = 0ms, Maximum = 0ms, Average = 0ms
```

Figure 9.2 Ping Test Statistics from the Laptop

The survey result of ping tests was attached on Appendix D. It is used to determine that there is connectivity between our computer and the remote destination computer. The ping test displays a report that includes the time it takes to receive a control packet from the remote host. High response time indicate low connection performances, while low response time means more reliable and faster connection.

Table 9.1 summarizes the round trip time from several IP address. From the collected data above, the average round trip time was calculated in terms of network section to compare the network speed of the two test cases above.

Table 9.1 Round Trip Time

Ping Test Result (One way)	Test 1	Test 2
Weather client to D-link access point	0.7ms	N/A
D-link access point to Weather server	0.1ms	N/A
Weather server to NCSU FTP server	0.95ms	N/A
NCSU FTP server to Weather server	0.95ms	N/A
Weather server to D-link access point	0.1ms	0.1ms
D-link access point to Weather client	0.7ms	0.7ms
Total trip time	3.5ms	0.8ms

In this experiment, it turned out that the second test is little faster than the other in data transmission speed because data transmission runs through only Wi-Fi network, not Internet line. Both options worked fine when a good wireless signal was supported.

Alarm functions in terms of a maximum wind speed were tested for the second case. The client's alert agent constantly monitored wind speed that is highly correlated with danger to the crane operation. Whenever the wind speed exceeds 20 miles per hour, the client's alert agent automatically triggered an alarm sound to let the crane operator be warned. In addition, this automatically created an email message and sent it to subscribers. Upon completing its tasks, the agent reported a daily weather summary to the subscribers through an e-mail every morning. NOAA (National Oceanic and Atmospheric Administration) provides seven day weather forecasts and information about weather related warnings, watches, and advisories. All of META data including RDU airport readings are updated every hour. It is not enough to use them as real time data. Those text files were also sent to clients as attachments to the automatic e-mail.

9.3 Range and Coverage of a 433 MHz Network

The weather station did not fit into our Wi-Fi network because the wireless sensors only transmit at 433.92MHz which is a totally different frequency from the 2.4 GHz Wi-Fi radio frequencies.

Data acquisition was performed by using the sensors placed on the roof of the existing plant by means of a 433 MHz wireless connection. Each sensor is working independently by the radio to communicate with a base station. During the initialization phase, the PC interface searches for all sensors and determines a small time window in which to activate the sensors. If initialization between the sensors and PC interface fails because of radio interference, the PC interface rescans for the entire sensor every 17 hours. During this period, any sensors added can be associated with the system. In this way, new sensors are automatically registered into the station.

According to the weather station manual, under optimum conditions, the radio-controlled sensors have an open field range of up to 330 ft when there is visual contact between the transmitter and the receiver. Concrete and steel walls can be passed through, but they do affect the radio coverage correspondingly.

The weather sensors were at first time deployed on the temporary stairway about 100 feet south of the receiver location, the control room of the existing Cates Plant. Even within a critical distance, there is no reception from the sensors because the radio transmission is disturbed by other equipment and two thick steel doors in the plant. From this outcome, it is confirmed that receiving failures occurs depending on interfering materials between the transmitter and receiver (i.e., thick walls, concrete, etc.) and the

distance between them. Subsequently a new location for the sensors was investigated and moved the sensors to the roof of the plants, about 30 feet apart from the place where the sensing receiver was located, to reduce the distance between the transmitter and receiver to the fullest. At last, error-free reception of data from the sensors was obtained.

To determine the coverage of a 433 MHz network, a site survey was performed with a small desktop weather station as a signal indicator as shown in Figure 9.3.

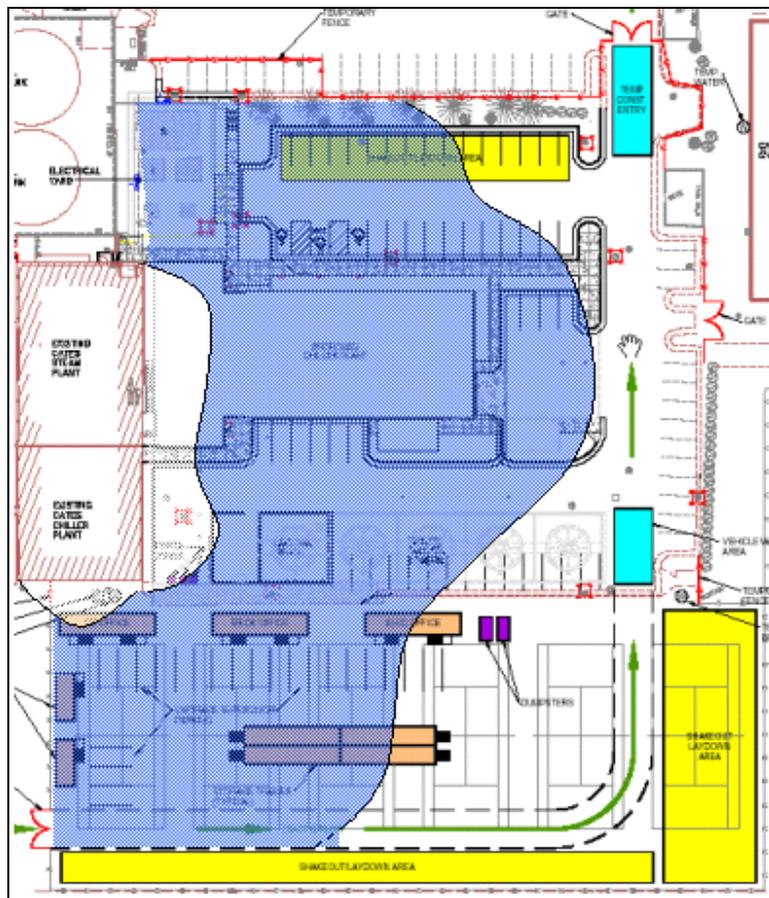


Figure 9.3 Coverage Tests of 433 MHz Network

The coverage area was filled with a blue color. The coverage area includes all areas where a radio connection was established between the transmitter and receiver. Most of the area was covered.

9.4 SONY Camera Agent Performance

The SONY wireless camera was placed on the roof of the Carmichael Activities Building to monitor the construction site with a battery and solar panels, and was set up for capturing and sending still images to the FTP server. The SNC-RZ30N is equipped with the Cisco Aironet 350 Series wireless LAN card inserted into the built-in Type II PCMCIA slot of the camera. The camera has a pan range of 340°, a tilt range of 115°, plus a 25x optical / 12x digital zoom (x 300 in total) capability.

This camera featured automated security tours, night vision with infrared technology, activity detection, and alarm trigger functions. The camera's images and the PTZ (Pan/Tilt/Zoom) functions can be controlled using any PC with Web browser at any location because it has a Web server capability. Up to 50 users can simultaneously access a single SNC-RZ30N camera to monitor images and control the unit. This camera can also be accessed and controlled via Compaq iPAQ-4155 handheld PDA. Jeode Java Virtual Machine is required to display an image from the camera and operate the camera.

The camera was working behind the D Link 614+ router with the private IP address 192.168.0.100 and the port number 1024. An outdoor test was performed to see if the camera can be associated with the D-Link 900 AP+ repeater. The camera had a poor connection with the D-Link 900 AP+ repeater where link quality was 42~100% and

signal strength 57~63%. Actual data transmission rate was measured at a different setting as shown in Table 9.2. The maximum data transmission rate of the camera is 9.4 Mbps for a 10/100 Base-T Ethernet interface, and 3.5 Mbps for the wireless interface. The frame rate (FPS) indicates the maximum number of frames that can be transmitted.

Table 9.2 Actual Data Transmission of the SONY Camera

Image Size	640x480	160x120	640x480	320x240
Image Quality Level	5	1	9	5
KByte/Frame	30	1	92	7.5
Frame per Second (FPS)	2	5	1	3
Data Rate(Kbps)	480	38	720	180
Link Quality Condition	57 (low) % ~ 63 (high) %			
Signal Strength Condition	42 (low) % ~ 100 (high) %			

As the image size was set to a higher resolution, a lower frame rate was obtained. A higher level gives a higher image quality, but the frame rate decreased as the image quality level increased. The number of frames actually transmitted varied depending on the network environments and camera settings (image size and image quality setting). Even though the frame rate was set at a maximum setting of 30 fps for smooth-moving images, it could not reach beyond maximum 5 Frame per Second (FPS) (from a choice of 160 x 120) due to bad network condition. Consequently, the throughput of the data transmission significantly decreased to 180 ~720 Kbps.

It is concluded that camera performance was significantly affected due to bad network condition (e.g., the frame rate and actual bandwidth were reduced).

As stated before, the camera was run on a battery and solar energy chargers because conventional electrical power was unavailable at the jobsite. As a result of a test operation, it turned out that this solar system was operational during approximately 5~6 hours a day on average as shown in Table 9.3.

Table 9.3 Turn-On Time Measurement of the SONY Camera

Date	3/7	3/8	3/9	3/10	3/11	3/12	3/13	3/14	3/15
Start (1)	Not work	11:56	13:28	11:28	12:24	10:35	10:02	Not work	10:12
End (2)		16:37	17:54	16:58	15:38	17:25	18:32		18:24
Turn on time (2-1)		04:41	04:26	05:30	03:14	06:50	08:30		08:12
Sky condition	cloudy	partly sunny	partly sunny	mostly sunny	partly sunny	mostly sunny	sunny	cloudy	sunny

Depending on the sky condition during the day (sunny or cloudy), the camera turn-on time varied from 3 to 8 hours. Even though it was battery operated, it did not continue to provide back up power in the dark because the solar cell did not provide enough power during the day for the battery to work at night. After the SONY camera remained in operation for several weeks, it was found that this camera has a problem with network connectivity. It is assumed that repetitive power on-and-off due to continuously changing weather conditions caused the hardware problem.

9.5 Trial Operation of A Web-based Information Portal

A combination of push-pull based data delivery should be well suited for efficient data capturing and dissemination. Unlike the crane alert agent where alerts are being pushed to the client, the Web-based approach allows weather data to be pulled whenever

needed. In order to test this concept, a pull-based Web-based information portal was developed and operated that allowed remote project participants to view and operate wireless cameras, download video clips, and leave messages.

After the end of the 3-month trial operation, it was found from the Web counter embedded in the main page of our portal that our portal had been visited 320 times during the 3 months. In addition, a simple online poll was built into the main page of the portal to establish people's opinions about which module among several units (i.e., SONY camera, wireless weather station, Netcam camera, communication board, etc) was most useful to their job. The result shows that users were most interested in the SONY wireless camera which has PTZ (Pan/Tilt/Zoom) function.

9.6 Multi-Media Communication Support System

The multi-media communication support system was demonstrated and applied to communication between a foreman at the work place and an expert at the designer office.

The remote expert accessed the D-link network camera to see real time video via our 802.11b wireless network already developed, and recognized visual features. This D-link camera automatically transferred and saved images into the laptop via the Wi-Fi network. These images were also accessible to the remote expert at a convenient time through the Internet. The remote expert can direct which point the camera should pay particular attention to and what to do in order to solve problems via video/audio link with the Internet. The quality and speed of the video from the camera was very good enough to support real-time communication between them.

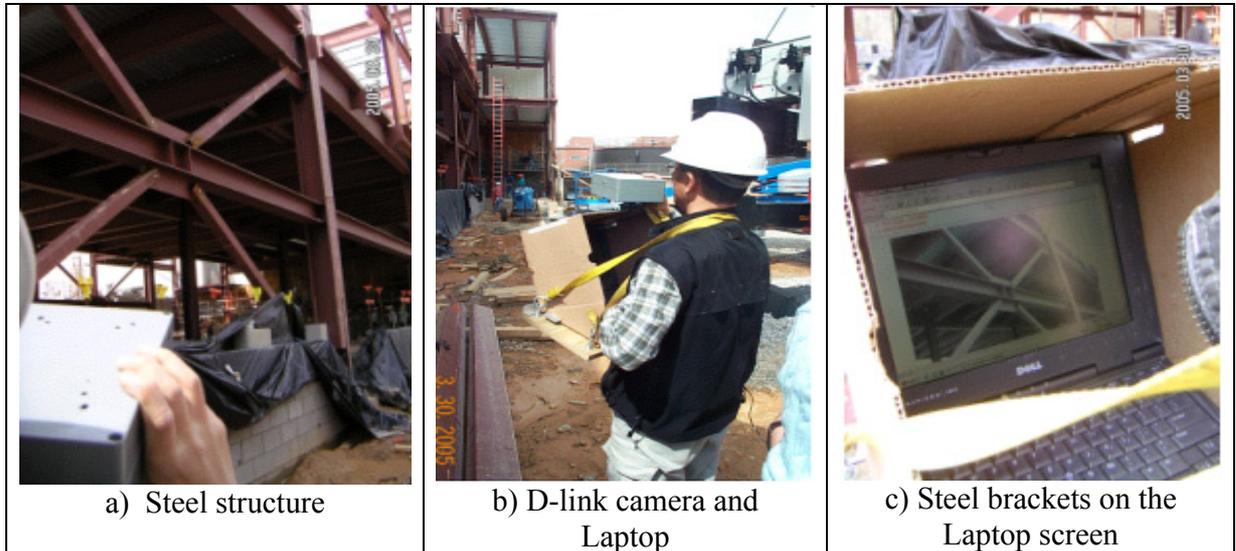
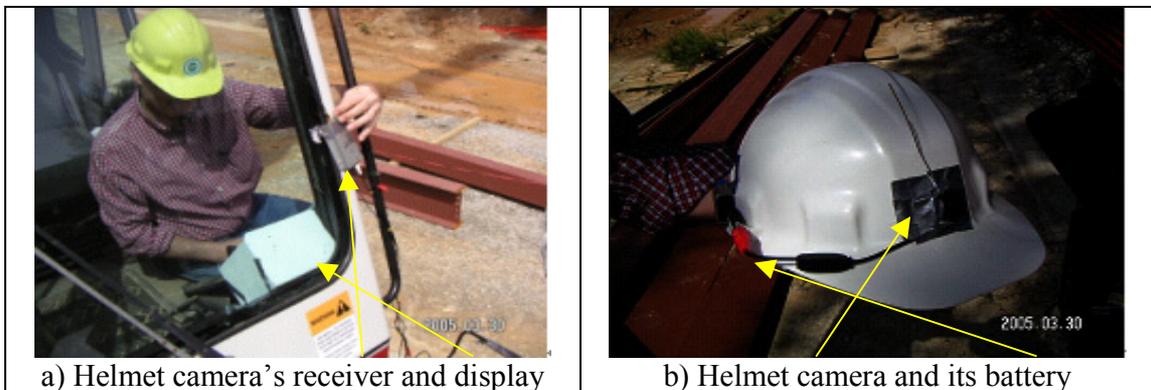


Figure 9.4 Multi-Media Communication Support System

To establish the audio link, a remote expert with Desktop PCs made an Internet phone call to the steel foreman equipped with the laptop on the jobsite by using Yahoo Instant messenger service. It was noted that if the remote expert's operating system is other than Windows 2000, PC-to-PC Internet phone service does not work. To overcome this interoperability problem, PC-to-Phone service provided by Yahoo was tested. The PC-to-Phone test provided more reliable connection and better quality of speech than the PC-to-PC test. However, it was found that the quality of speech in both cases is not high enough to talk for a long time compared to a normal phone.

9.7 Multi-Media Augmentation System

The multi-media augmentation system was tested for safe crane operation at the laydown area as shown in Figure 9.5. The helmet camera was mounted on the ground worker's helmet to give the operator the best possible view of areas under the load. The helmet camera collected multi-media information (sound and video) from the steel laydown area and had it fed into a full color compact monitor located in the crane cabin. The helmet camera used a 900MHz frequency to communicate with the receiver via a wireless link. The quality of the video from the helmet camera was moderately good within the range of approximately 60 ft, but severely affected beyond that range. While lifting steel components, the crane operator can clearly listen to what the worker talks to him with 1-way microphones embedded on the helmet camera.





c) The helmet camera monitoring truss work on the laydown area



d) Compact display inside the crane cabin

Figure 9.5 Multi-Media Augmentation System

10. VALUE ASSESSMENT OF WI-FI AGENT FUNCTIONS FOR THE CATES PLANT

The objective of this chapter is to analyze the values of the field-tested Wi-Fi agent functions. Because of the multifaceted benefits of the various applications, the flexible value concepts discussed in chapter 2.9 will be utilized in this analysis. The value assessment will be presented applying six different value measurement techniques organized according to the following Wi-Fi functions: A) Alert agent, B) Ubiquitous site inspection, C) Ubiquitous problem solving, D) Ubiquitous sensing and data access, and E) e-Document Management. At the end of each function analysis, a short summary of the different outcomes will be offered.

10.1 Agent Functions as Perceived Opportunities

The survey results discussed in section 4.5 highlighted the values associated with various opportunities for using Web-based technologies in construction. Table 10.1 presents an attempt to link those opportunities with the five agent functions presented in Table 10.2, “value-matrix chart”.

Table 10.1 Perceived Opportunities associated with the five agent functions

Explanation	Rank	Function
Send and receive design/shop drawings electronically.	1	E
Receive design approvals electronically.	2	E
Monitor the construction site 24/7 on the computer screen or pocket PC.	9	B, C, D
Obtain automatic records of temperature, humidity, wind, etc. in and outside.	12	D
Record automatically 3 minute time-lapse movie of an entire work day.	13	B, C, D
Establish an automatic record of information exchange between project participants.	5	C, E
Receive real-time status information about material supply trucks + load (e.g., steel).	7	A, B, C, D
To monitor the implementation of safety rules including recording perfect conditions.	10	B, E
Provide real time information to anybody on site (i.e., CAD, safety rules, and material location).	4	C, E
Training of crews, foremen, and managers.	6	E
Provide real-time collaboration between project participants (video and audio).	8	C
Provide the owner with a visual “as-it-built” documentation including visual inspections.	3	D
Having a 24/7 “security fence” with automatic monitoring/capturing system.	11	A, D
Replace weekly site meetings with real-time Web-postings and video conferencing.	14	C

Respondents answered that document management related factors hold higher opportunities for Web-based communication than others. On the other hand, the problem solving function (Function C) is considered as the most widely perceived opportunity among the five functions.

10.2 Value Assessment Matrix

Table 10.2 presents an overview indicating which methods are used to assess each Wi-Fi function A-E.

Table 10.2 Value Assessment Matrix

		A	B	C	D	E
Function		Alert Agent (AA)	Ubiquitous Site Inspection (USI)	Ubiquitous Problem Solving (UPS)	Ubiquitous Sensing and Data Access (USDS)	e-Document Management (UDM)
Value Method						
1	Decision tree analysis	A1				
2	Cost-benefit analysis	A2	B2	C2		E2
3	Break-even analysis		B3	C3		
4	Sensitivity analysis	A4	B4	C4		
5	Weight-value matrix				D5	
6	Cost-utility analysis					E6

Different scientific methods will be used to measure the values of Wi-Fi agent functions. Each investment situation is unique and requires diversified investment choices. Therefore, in today's complex and dynamic construction environments, it is risky to rely on one method. It is necessary to use multiple methods and compare their output against each other. The following sections will discuss each intersection of the matrix box above.

10.3 Function A : Alert Agent

The value of this site integrated alarm system, able to forecast wind speed at the location of a crane, is its capability to warn the crane operator while he is focusing on the job at hand. Thus, it will reduce the risk of accidents caused by an unexpected wind gust with preset alarm thresholds, which initiate countermeasures if transgressed. However, it is very difficult to estimate the benefits of this function with cost-benefit analysis only because the probability of damage is strongly correlated with the great uncertainties in a crane accident resulting from unpredictable weather conditions. There are technological uncertainties due to possible system failure. Furthermore, improper use of alarm thresholds can result in false, late, and/or failed alarms, which can lead to very serious situations.

10.3.1 Decision Tree Analysis (A1)

This value assessment technique provides a structured approach to determine the expected monetary value of the wind alarm system based on probability. Furthermore, by varying the probability, its sensitivity to the assumption can be analyzed.

It is apparent that the effect of the alert agent (A) is to lower the probability of having a crane accident caused by wind. Figure 10.1 presents a tree-based layout of possible two outcomes: install or not install Function A.

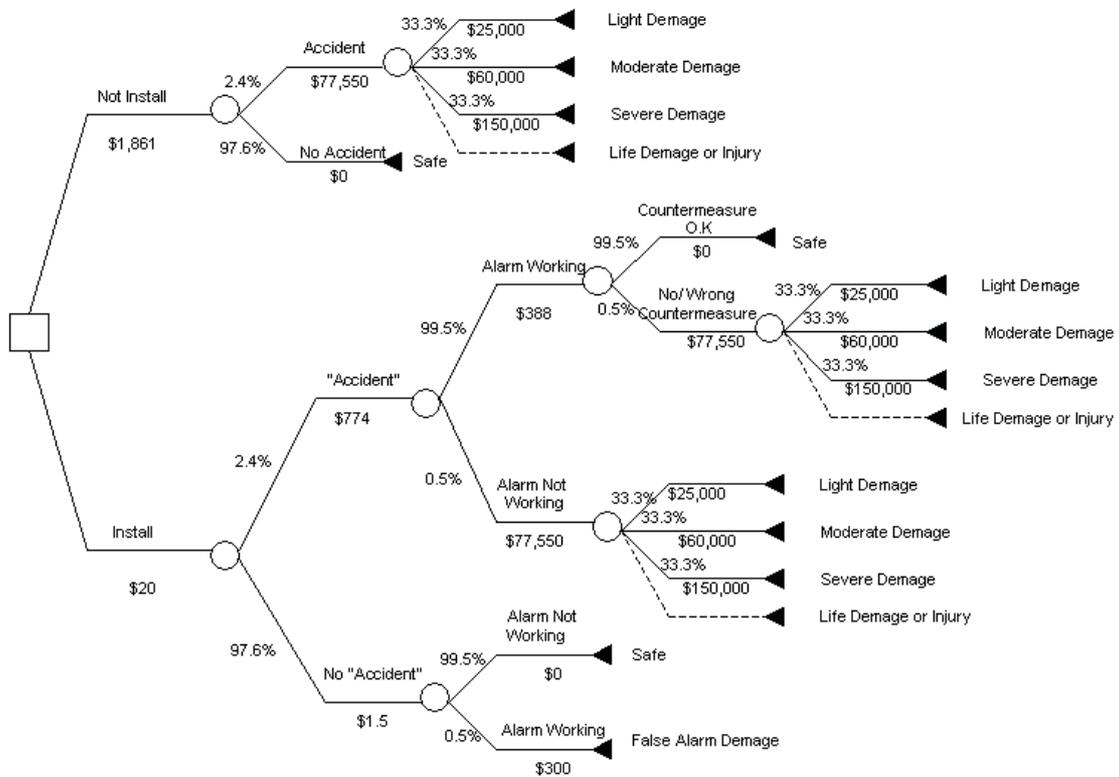


Figure 10.1 Decision Tree for Function A

The baseline assumptions made for calculating the expected cost include:

- Probability of wind related crane accident: 2.4/100.
- Probabilities of a severe, moderate, and light damage cost of crane accident: 33/100, 33/100, and 33/100, respectively.
- Probability of alarm working: 99.5/100.
- Probability of a countermeasure succeeding: 99.5/100.
- Expected value is calculated in a yearly basis.

Using the common nomenclature of decision tree analysis, the possible probability associated with the event are labeled above each path. Damage costs are assigned to final possible outcomes. The value of uncertain outcomes for each node is calculated by multiplying the value of the outcomes by their probability and recorded along each path.

A damage cost due to crane accident has one of three outcomes: 1) severe, 2) moderate, and 3) light. The estimated cost of these outcomes would be \$25,000, \$60,000, and \$150,000, respectively, with probabilities of 0.33 each. The degree of damage cost is influenced by a variety of factors, including the extent of the damage and the location of the accident. Any cost estimates derived from information provided here was rounded to indicate that they are only approximations, not exact figures. The recommended rule is: for estimates less than \$40,000, round to the nearest \$25,000; for estimates between \$40,000 and \$100,000, round to the nearest \$60,000; and for estimates greater than \$100,000, round to the nearest \$150,000.

This direct costs associated with a single crane accident per year involve any collateral damage to property and structures, equipment downtime, loss of production, and workers' compensation claims which cover medical costs for an injured or ill worker. Most importantly, injuries or a possible fatality are not considered in the calculation, but are included in the final analysis. Indirect costs would include the costs to train and compensate a replacement worker, and to maintain insurance coverage. Intangible costs represent the costs to which cannot be assigned an explicit price such as pain, suffering, loss of companionship, lower morale, and poorer customer relations, which are associated with quality of life.

As can be seen from Figure 10.1, the expected monetary value (EMV), weighted sum of all the cost consequences, calculated for two cases are \$1,861 and \$20 respectively. This difference can be used as a criterion for deciding whether or not to install Function A. It is apparent that the possibilities of having an accident depend on many factors that are related to the actual situation such as the experience of the operator, the condition of the crane, etc. In order to investigate the impact of different probability, detail sensitivity analysis could help in quantifying the extent of the impact (see section 10.3.3).

10.3.2 Cost-Benefit Analysis (A2)

A cost-benefit analysis with both costs and benefits expressed in monetary terms provides economical value of Function A. It is assumed that the hardware of Function A becomes obsolete 1 year after use.

Table 10.3 Cost-Benefit Analysis of Function A (Based on 1 year economic life)

Costs	Weather Alarm Station with sensors 1 each	\$ 600	
	PC Interface	\$ 200	
	Installation cost (1 year)	\$ 300	
	Maintenance cost (\$60 per 1 month)	\$ 720	
	Total Cost		\$ 1,820
Benefits	Difference in EMVs		\$ 1,841
Benefit to Cost Ratio = \$ 1,841/ \$ 1,820 = 1.01			
Net Benefits = \$ 1,841- \$ 1,820 = \$ 21			

The difference between EMVs calculated in section 10.3.1 is used as benefits of Function A. As indicated in Table 10.3, the total investment cost of Function A is \$1,820. It should be factored into the calculation. The benefit to cost ratio is 1.01 and net benefits \$21.

10.3.3 Sensitivity Analysis (A4)

As argued in 10.3.1, the probability of having a crane accident depends on many factors. Sensitivity analysis provides the opportunity to investigate how the benefits vary along with changes in key parameters. Table 10.4 presents the outcome of such analysis for the different probabilities of accident between 1~5% along with different probabilities of damage severity.

Table 10.4 Net Benefits Calculation of Function A at various probabilities (Cost unit: Thousand Dollar)

Accident Probability	Probability Distribution of Damage Severity (Light-Moderate-Severe), %	EMV (Not Install) (1)	EMV (Install) (2)	Difference in EMVs (3) = (1)- (2)	Function A Cost (4)	Net Benefits of Function A = (3)-(4)
1%	19-33-48	966	11	955	1,820	-865
	33-33-33	775	9	766	1,820	-1,054
	48-33-19	603	7	596	1,820	-1,224
2%	19-33-48	1,931	21	1,910	1,820	90
	33-33-33	1,551	17	1,534	1,820	-286
	48-33-19	1,206	13	1,193	1,820	-627
3%	19-33-48	2,897	30	2,867	1,820	1,047
	33-33-33	2,327	25	2,302	1,820	482
	48-33-19	1,809	19	1,790	1,820	-30
4%	19-33-48	3,862	40	3,822	1,820	2,002
	33-33-33	3,102	32	3,070	1,820	1,250
	48-33-19	2,412	25	2,387	1,820	567
5%	19-33-48	4,827	50	4,777	1,820	2,957
	33-33-33	3,878	40	3,838	1,820	2,018
	48-33-19	3,015	31	2,984	1,820	1,164

As shown in Figure 10.2, if the accident probability consequences for the three scenarios of the probability distribution of damage severity are more than about 1.90% (19-33-48), 2.35% (33-33-33), and 3.05% (48-33-19) respectively, Function A is justified. There exists a linear relationship between the accident probability and the expected benefits for each scenario depicted in Table 10.4. The higher the accident probability, the larger the difference in the net benefits of the two end scenarios. This means that the scenario of 19-33-48 is more sensitive to the change in the accident probability than the other two.

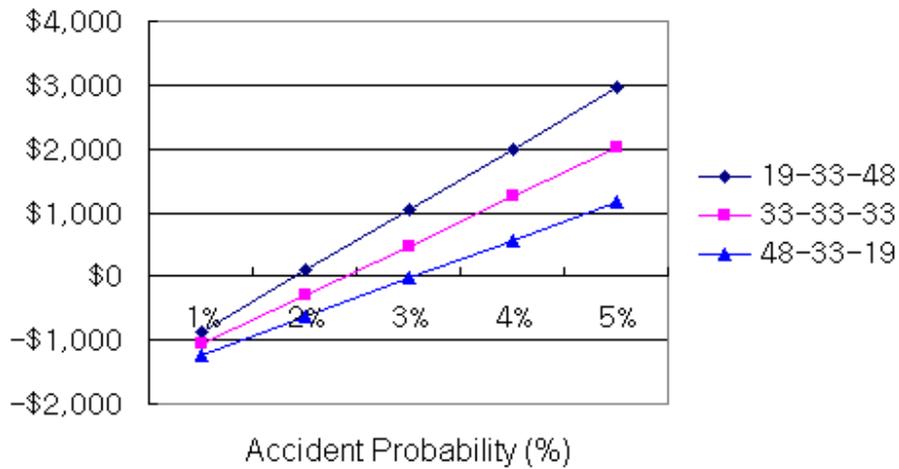


Figure 10.2 Net Benefits at various probabilities of accident and damage severity

10.3.4 Ancillary Values

This section will sum up the many ancillary values that can be derived from having the core system components installed on a construction site. The list includes the following items.

1) Integrated with Web-based wireless technologies, Function A allows users anywhere to collect data from the alert agent server into their local client computer to process alarms and trigger automatic e-mail notification, in close to real time (i.e., within a couple of minutes from the time of the environmental event).

2) In addition, the foreman equipped with wireless laptops can be able to make sound decisions based on the information provided by weather agents (i.e., wind speed and rainfall) to avoid unnecessary risk to its people and equipment.

3) The data from the alert agent can also be kept in automatic records for future reference. This system allows users to review current and historical data from the sensing sites, providing a basic data for weather-related claims and disputes for the post-construction stage.

10.3.5 Summary

Several studies show that crane operations can easily cause severe accidents. For this reason, Function A can address serious risk resulting from a high wind gust, alerting a crane operator to an impending wind-related hazard. Following are the key descriptions.

1) Compared to other functions of Wi-Fi agent system, Function A is a simple and inexpensive off-the-shelf product, costing around \$1,820.

2) Expected monetary values depend on many uncertainties such as probability of crane accident, probabilities of damage severity, damage cost by each severity, etc.

3) Undoubtly, if employee injuries or fatalities are considered in determining the damage cost, the benefits of Function A will far outweigh its cost.

10.4 Function B : Ubiquitous Site Inspection

Function B addresses the need for three common types of inspection: 1) Structural, 2) material, and 3) safety. A structural inspector compares design documents with the actual installation. In several locations during our research, the structural inspector, Mr. Russel Wahrman, was faced with an unclear design document, requiring him to get

clarification from the designer (situated in Durham). A material inspector verifies that a material (e.g., concrete) meets the requirements of the applicable specification. A safety inspector identifies potentially hazardous situations and supervises compliance with safety regulations. The suitable implementation of Function B returns savings in travel cost and time from the jobsite to the site inspector's remote office as well as inspection time. Baseline assumptions are formulated to calculate annual benefits.

- 30 % of the total site inspections can be remotely supported by the Function B.
- Function B can save at least 30 minutes of inspection time per inspection.
- The frequency of site inspection: two times per week.
- Driving distance: 80 miles.
- Average driving cost per mile: \$0.36*.
- Average cost per man-hour of the site inspector: \$70** (U.S. Department of Labor).
- The hardware of Function B becomes obsolete 1 year after use.

Based on assumptions above, the annual benefits of this function are projected in Table 10.5.

Table 10.5 Benefits Calculation for Function B

Driving Cost	$80\text{miles} \times \$0.36 \times 4\text{week} \times 12\text{month} \times 30\% \times 2$ (inspection frequency)	\$829	
Travel Time Cost	$80\text{min}/60 \times \$70 \times 4\text{week} \times 12\text{month} \times 30\% \times 2$ (inspection frequency)	\$2,688	
Inspection Time Cost	$30\text{min}/60 \times \$70 \times 4\text{week} \times 12\text{month} \times 30\% \times 2$ (inspection frequency)	\$1,008	
Total Cost per Inspector			\$4,525

* Mileage rate is based on a requirement for travel reimbursement at NC state University.

**Mean hourly wage is calculated from $(\$74,790/2,080\text{ hours}) \times 2$ (Indirect cost rate).

This includes all benefits that can be identified directly to the system. In addition to the direct benefits, there are also several possible indirect benefits (e.g., fast turnaround time to complete inspections) involved in system implementation. However, it is extremely hard to quantify indirect benefits in term of dollars.

10.4.1 Cost-Benefit Analysis (B2)

From the calculated benefits above, the cost-benefit analysis mentioned in section 10.3.2 is conducted to show the economic impacts of Function B. The hardware & software costs are based on actual installation at the case project. Time and effort for the researcher to install and maintain the system are considered in calculating the function cost.

Table 10.6 Cost-Benefit Analysis for Function B (Based on 1 year economic life)

Costs	Hardware	D-link 614+ Router 1each	\$130		
		D-link 800AP Repeater 1each	\$100		
		D-link 900AP Repeater 1each	\$100		
		D-Link ANT24-0801 8.5dBi Pico Cell Patch Antenna 1each	\$170		
		Multimedia Headset with Mic.	\$50		
		ICS Server Computer 1 each	\$1,000		
		D-Link Mobile Network Camera (DCS-1000W) 1each	\$450		
		Network Camera (StarDot's NetCam)	\$850		
		Network Camera (Panasonic KX-HCM270)	\$600		
		D-Link DWL-650 Wireless Cardbus Adapter 1each	\$50		
		Additional network card for ICS server	\$50		
		Sony Camera System	Zoom Camera	\$1,400	
			Cisco Aironet Card	\$150	
			Camera Enclosure	\$700	
			Car Battery	\$150	
Solar Panel (20W)	\$250				
	Power Control Kit	\$150			
Sub Total			\$6,350		
Installation Cost (1 year)		\$500			
Maintenance Cost (\$60/ 1 month)		\$720			
Total Cost			\$7,570		
Benefits	Remote Site Inspection (3 inspectors)	Driving cost	\$2,488		
		Travel time	\$8,064		
		Inspection time	\$3,024		
	Total Benefits			\$13,576	
Benefit to Cost Ratio = \$ 13,576/ \$ 7,570 = 1.79					
Net Benefits = \$ 13,576 - \$ 7,570 = \$ 6,006					

Data shows that for every dollar invested in Function B, it returns almost \$ 1.79 generating the maximum net benefits of \$ 6,006 after one year of implementation.

Depending on the size of the project and the location of inspectors' office, the benefits of Function B could be much greater than calculated.

10.4.2 Sensitivity and Break-Even Analysis (B3&B4)

Figure 10.3 points out how the combination of an average driving distance and a frequency of site inspection varies with changes in reduced site inspection times. Nine different scenarios were plotted in terms of reduced inspection times. These scenarios included 1(time of inspection per week)-40 (miles), 1-80,1-160, 2-40, 2-80, 2-160, 3-40, 3-80, and 3-160.

The line of 3 times of inspection per week (thick dotted line) has a slightly steeper slope than line of 1 (solid line) or 2 (thin dotted line) times of inspection per week. It means that the changes in benefits in terms of 3 times of inspection per week is more susceptible to changes in reduced site inspection times than the other two. However, changes in benefits in terms of a driving distance are indifferent to changes in reduced inspection times.

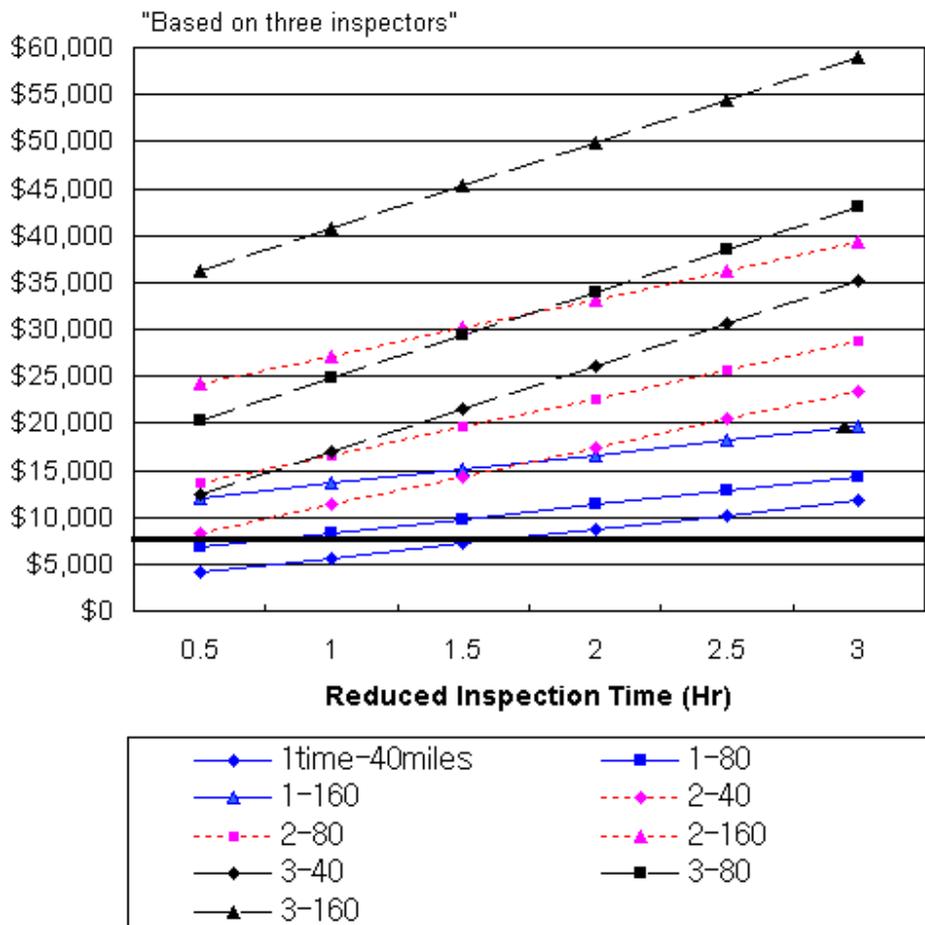


Figure 10.3 Cost-Benefits Chart for three inspection variables

As seen in Figure 10.3, the two intersections between the cost and benefits line (i.e., break-even point) appear at the point of 1.6 reduced inspection hour in the case of 1 times-40 miles and at 0.75 in 1 time-80 miles.

10.4.3 Ancillary Values

The ancillary values from Function B revolve around use of wireless cameras and the Wi-Fi network installed on the jobsite. Due to the flexibility of the system, its applications are limitless. Following are some apparent ones.

1) Material suppliers are able to check the status of inventory level and work in process to better plan the delivery and staging of structural members.

2) Construction managers and a foreman are capable of monitoring multiple workers' field of views through wireless cameras.

3) Associated with Function D, Function B allows for the creation of automatic records of as-built information from cameras and sensors. Historical archives can be used to solve claims and disputes that may occur after the process has been completed. Especially pictorial information is able to be used as a training tool for inexperienced workers to learn from past projects.

10.4.4 Summary

Omni-present Wi-Fi networks offer a wide variety of beneficial use in the area of site inspection. The enabling conditions are a set of sensors and agents that provide necessary information via Internet. Following are four key observations:

1) It is feasible to conduct remote visual inspection using real-time video/audio with fixed and mobile cameras.

2) A large portion of on-site inspections can be executed visually. Function B allows three independent off-site inspectors (i.e., structural, material, and safety inspector) to reduce their field report-writing times, site inspection times, driving costs, and travel times because of automation.

3) Low costs leads to the low break-even point in the cost-benefit chart in Figure 10.3.

4) Vital benefits of remote site inspection are to assure worker safety in a complex and sometimes dangerous workplace environment.

10.5 Function C : Ubiquitous Problem Solving

As mentioned in the previous chapter, inaccurate drawings and structural pieces result in costly problems because they commonly require significant time and effort to find solutions (e.g., RFI process). With Function C, field personnel will have direct access to any information from off-site experts who have more experience, or are able to solve design problems or other errors, using integrated Wi-Fi communication tools. An obvious benefit of Function C is a reduction in travel cost and RFI processing time. To determine number of RFIs cases for our case project, the RFIs log was examined. The RFIs log maintained 241 RFIs during 5 months between many different companies as shown in Appendix E. Most of the RFIs were generated between Gilbane Building Co. and RMF Engineering, Inc. Based on this information, the following baseline assumptions are formulated.

- 1 hour of RFI processing time can be saved by the use of Function C.
- The frequency of an on-site visit is one visit every 4 RFIs.
- 100 % of total site visits can be remotely supported by the Function C.
- Average cost per man-hour of an engineer: \$ 96 (U.S. Department of Labor).

Based on assumptions above, the benefits of Function C are calculated in Table 10.7.

Table 10.7 Benefits Calculation for Function C

Driving Cost	80 miles × \$0.36 × 241RFI × 12/5 × 1visit / 4 RFIs (visit frequency)	\$4,164	
Travel Time Cost	80 miles/60 × \$96 × 241RFI × 12/5 × 1visit / 4RFIs (visit frequency)	\$18,509	
RFI Processing Time	1hour × \$96 × 241RFI × 12/5 × 1visit /4 RFIs (visit frequency)	\$13,882	
Total Cost per Engineer			\$36,555

**Mean hourly wage is calculated from (\$99,715/2,080 hours) × 2 (Indirect cost rate).

Indirect benefits (e.g., reduction in construction downtimes or RFIs turnaround times) are not considered in this analysis due to difficulty in quantifying cost.

10.5.1 Cost-Benefit Analysis (C2)

Based on Table 10.7, the total cost and benefits are calculated in Table 10.8 to calculate the economic impacts of Function C.

Table 10.8 Cost-Benefit Analysis for Function C (Based on 1 year economic life)

Costs	Same as the cost of the Function C plus 1 set of Head mounted camera (\$1,000)		\$8,570
Benefits	Remote Problem Solving (1 Engineer)	Driving cost	\$4,164
		Travel time	\$18,509
		RFI Processing Time	\$13,882
	Total Benefits		
Benefit to Cost Ratio = \$ 36,555 / \$ 8,570 = 4.2			
Net Benefits = \$ 36,555 - \$ 8,570 = \$ 27,985			

From the data in Table 10.8, the benefits to cost ratio is 4.2 and the total benefits of Function C is \$ 27,985 more than its total cost.

10.5.2 Sensitivity and Break-Even Analysis (C3&C4)

In this section, sensitivity analysis is conducted to determine the impact of changing a driving distance on changing a site visit frequency. Three different scenarios were plotted in terms of one site visit per RFIs numbers (i.e., site visit frequency). These scenarios include 40 (miles), 80, and 160.

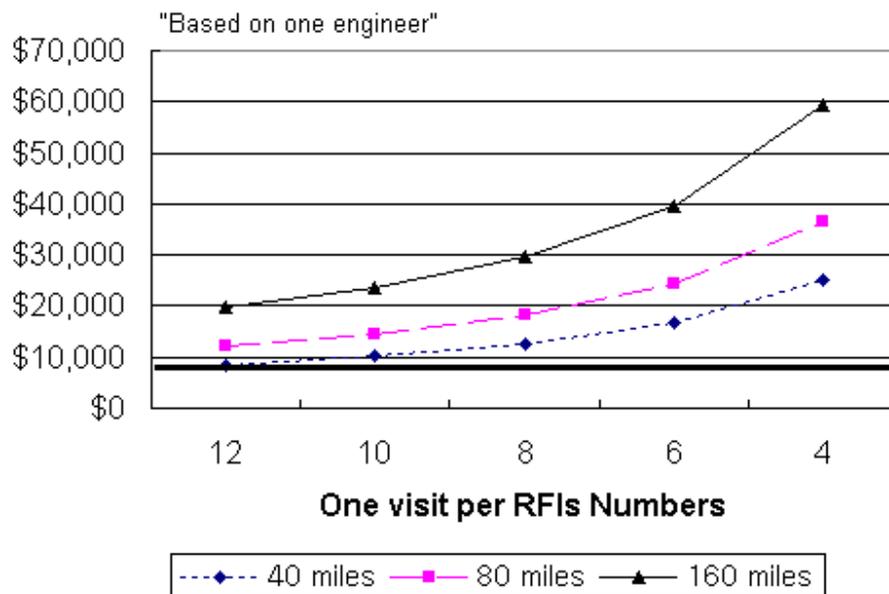


Figure 10.4 Cost-Benefits Chart for two variables

The upper graph shows that the more distant from the jobsite, the more sensitive to the site visit frequency the results will be. It also shows a logarithmic increase in total benefits as one site visit per RFIs numbers decreases. If the frequency of site visit (i.e., one site visit per RFIs numbers) for the 40 miles scenarios less than about 1/12, in the first year total benefits equals total costs resulting from the travel between site and office.

10.5.3 Ancillary Values

While the discussed situation represents a case of an off-site expert, many opportunities exist for omni-present connection to on-site experts (today, limited to walkie talkie). Following is the list of ancillary values.

1) A crane operator is able to get a clear view of the load as well as communicate with ground workers or connectors to avoid accidental contact with nearby steel structures.

2) Similarly, when erecting steel components, a foreman can have the best possible view of areas under the load to monitor how steel erectors work and give some instructions to the workers.

3) Most importantly, Function C can be used as an augmented tool to reduce on-site meeting time and frequency by adding digital tools such as a instant messaging and ubiquitous live video.

10.5.4 Summary

The strength of a human-to-human communication concept is capable of connecting all construction personnel to the critical source of information at the same time.

1) RFIs process can be augmented by the use of Function C, providing remote workers a real-time video and audio link with the Internet.

2) With this system, the ability to quickly resolve construction claims and shorten the time for RFIs will bring other benefits, but these are very difficult to determine.

3) Due to the difficulty in assessing indirect and intangible costs, most economic analyses used in this chapter focus on the measurement of direct costs and benefits.

However, indirect and intangible costs and benefits are equally important and need more in-depth exploration.

10.6 Function D : Ubiquitous Sensing and Data Access

In this section, three state-of-the-art sensing alternatives in construction are briefly described before their benefits are compared in terms of several qualitative factors.

First, a ubiquitous machine (e.g., backhoe) monitoring function can be used to monitor its operations and locations. With the use of GPS and satellite communications, the sensor data attached to machines (i.e., location, engine temperature, fluid level, pressures, alarm states, etc.) is collected, transmitted to other machines or can be stored in a central server (MobileNet, 2004).

Second, it is necessary to observe on a regular basis the degree of damages or degradation of civil engineering structures (e.g., ground settlement) during or after construction. In this case, a remote site measurement function can be used to monitor the physical properties (i.e., settlement, displacement, stress, strain, etc.) of civil engineering structures scattered over a wide area, using wireless sensing and Internet technology (Yamamoto, 2002).

Third, this site measurement function can be integrated with the machine monitoring function to create a new valuable function at the construction site; for example, a 3-D machine control function can be employed to increase the efficiency of road graders used in highway construction. This 3-D blade control system automatically keeps the leveling blade of the road grader in the correct position, providing the machine

with three dimensional data about the position in space and distance to a target position in X, Y, and Z to control the spatial scope of its work (Heikkilä and Jaakkola, 2001).

The three state-of-the-art sensing alternatives are envisioned to enable real-time communication between machine and human (M2H). Use of available Internet technologies integrated with wireless sensor networks allows test and measurement data to be automatically captured from a distance, pre-processed, and aggregated to monitor and control machine and equipment on a real-time basis.

10.6.1 Weight-Value Matrix Analysis (D5)

Because most of the applications create new value, comparative economic data is hard to combine in this analysis. For this reason, a weight-value matrix is selected.

Figure 10.5 presents the weight-value matrix chart for comparing three alternatives, using six performance criteria A-F. The most left column shows a set of performance criteria. The evaluation score for each alternative is calculated through the use of a numerical scale with a range from 0 to 5.

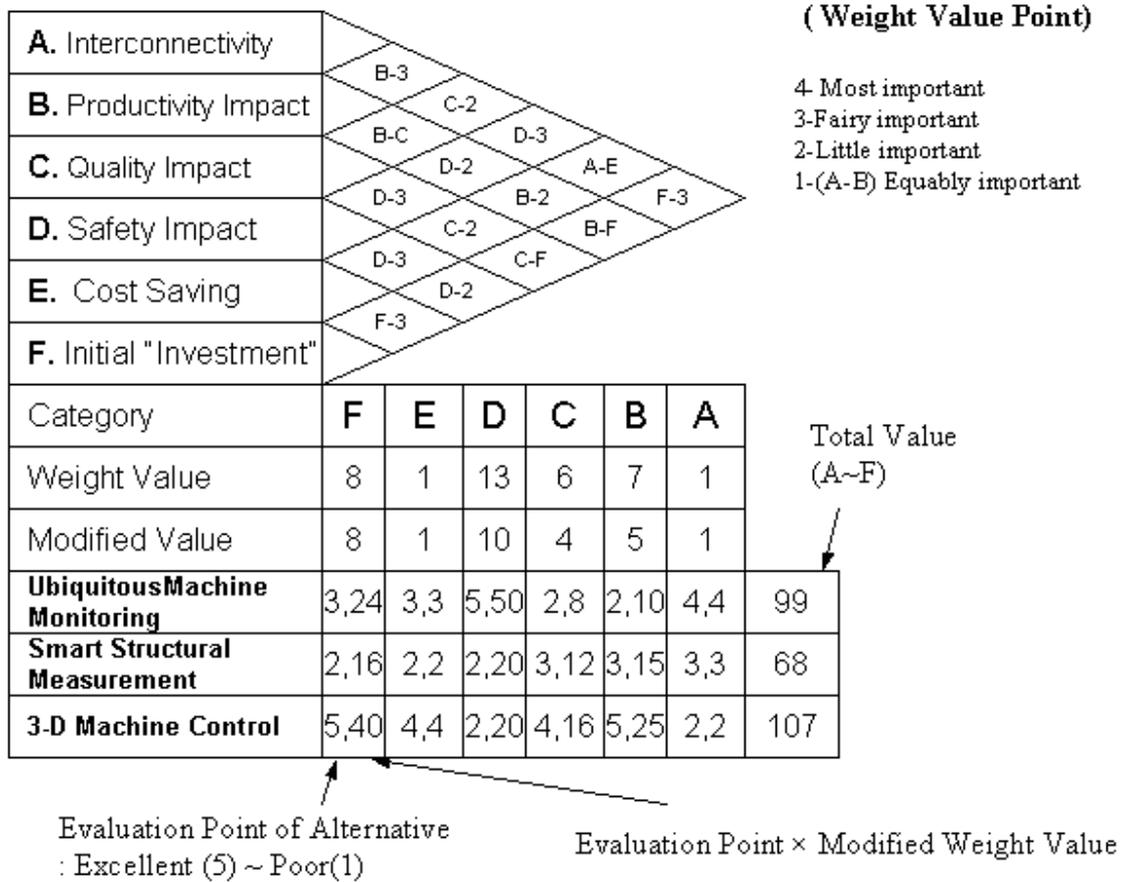


Figure 10.5 Weight-Value Matrix Chart

As a result, the ubiquitous machine monitoring approach earns 99 points, while the remote site measurement earns 68 points and the 3-D machine control earns 107 points. This implies that the combined approach (i.e., 3-D machine control) provides better performance than the other two, based on the established criteria.

10.6.2 Ancillary Values

1) From a maintenance viewpoint, remote equipment monitoring is another important value for assuring safety, improving the quality of inspections, and reducing maintenance costs.

2) Dynamic behavior of long bridges, structural soundness monitoring of poured concrete, and environmental data recording related to fumes and noise will be useful to improve the efficiency of inspections executed by regulatory agencies such as OSHA and EPA.

3) Operator skill assessment using sensor data collected at equipment joysticks will help support operational training and safety, leading to lower machine cost.

10.6.3 Summary

The following are key observations:

1) The Function D provides a common set of test and measurement data from all different remote sensors and allows users to retrieve real-time and easy-to-access field data. This ensures reliable information, enhances safety, and saves time through automation.

2) A weight-value matrix analysis is used to ascertain the overall unquantifiable value of alternatives, but developing performance criteria and defining their mutual importance weight is very critical to maximizing the gains of this analysis. Furthermore, assigning an evaluation score to the each of alternatives can be subjective and dependent on a particular person's preference. Thus, more people should take part in a

brainstorming or Delphi decision process to ensure greater reliability in the evaluation of alternatives.

3) Function D can be easily augmented as a tool to cover remote testing associated with material inspection (Function C).

10.7 Function E : e-Document Management

This Function will address bottleneck in the shop-drawing approval process of structural steel construction. As shown in Appendix E, the submittals log maintained six shop-drawing packages between Dave Steel Company and RMF Engineering, Inc. during the shop-drawing approval stage. It was learned that the main reason for the designer and contractor to use e-drawing is that they do not have a large enough screen to see blue print drawings. Recent technology, however, provides new affordable means to allow for touch screen representation without need for scaling. With Function E coupled with Web-based technologies, designers can easily check e-drawings on a large flat and touch screen. If a modification is required, it can be completed online and sent to the next party involved in the approval process in real time.

The costs for a traditional paper-based document delivery are calculated based on the following assumptions.

- Five sets of drawings are reproduced by a steel supplier.
- Plan-printing price for one set of drawings (30 sheets) is \$65.
- Typical UPS Rate (from Asheville to Raleigh) associated with sending a 20lbs tube of drawing package to each party involved in the approval process NC is \$60.

-The hardware of Function E becomes obsolete 1 year after use.

Based on the assumptions above, the comparative costs for each alternative are summarized in Table 10.9.

Table 10.9 Cost Calculation for Function E (Based on 1 year economic life)

Traditional Paper-Based Approach	Printing Cost (Structural drawing)	10 drawing packages × 5 sets × \$65	\$3,250	
	Delivery Cost (Structural drawing)	10 drawing packages × 5 sets × \$60	\$3,000	
	Total Cost			\$6,250
e-Document Delivery	Computer (Wi-Fi)		\$1,000	
	Large Touch Screen (65inch) 2 each		\$20,000	
	Total Cost			\$21,000

10.7.1 Cost-Benefit Analysis (E2)

In this section, the cost-benefit analysis is used to determine the impact of economic feasibility on Function E. According to the data in Table 10.9, the total cost of \$6,250 for the traditional paper-based approach is only for structural drawing.

Considering the reproduction cost for mechanical, piping, and foundation drawing package, the total cost increases up to \$25,000 ($\$6,250 \times 4$). This cost can be considered as total savings because Function D can eliminate the need to deliver design documents through traditional transportation.

The benefit-cost ratio is calculated to be 1.19 ($\$25,000/\$21,000$), which means that Function E is economically feasible, generating a net-benefit of \$4,000. Higher savings will arise during actual construction as a result of implementation of the proposed

Function. Today, for example, steel construction includes 3 sets of different drawing packages that need to be available to the crews (i.e., shop drawing, erection drawing, and design drawing). The erection drawings are available at the foreman's trailer, while the shop drawings and design drawings are not available to the crews because they are only kept at the general contractor's office. During the steel erection, it was observed that the foreman spent an average of 3 hours a day on clarification caused by interference between similar jobs (architect, structure, and HVAC).

10.7.2 Cost-Utility Analysis (E6)

As stated in the previous section, it is very difficult to assess benefits of Function E in monetary terms (e.g., difficulty of determining benefits associated with turnaround time). Therefore, Cost-Effectiveness (CE) analysis is used to compare the relative cost effectiveness of various alternatives, which evaluates alternatives according to a comparison of their costs and their utility.

A set of four measures of effectiveness is constructed for each alternative and associated utility weights are derived. These importance weights reflect the relative contribution of each measure of effectiveness to overall utility. The evaluation score for each alternative is calculated through the use of a numerical scale with a range from 0 to 10.

Table 10.10 Cost-Utility Analysis for Function E

Function	Cost	Measure of Effectiveness								Overall Utility (Weighted Sum)		Cost/Utility Ratio	
		During Design (A)				During Construction (B)				(A)	(B)	(A)	(B)
		C	D	E	F	D	E	F	G				
Traditional Approach	\$25,000	3	2	3	2	2	3	2	10	2.7	6.2	\$9,259	\$4,032
Function E	\$21,000	10	9	9	8	9	9	8	3	9.3	5.8	\$2,258	\$3,620
Importance Weight		0.5	0.1	0.2	0.2	0.1	0.2	0.2	0.5				

C: Turnaround time, D: Data storage capacity, E:Searchability, F:Interconnectivity, G:Usability.

After weighing each measure of effectiveness by the corresponding importance weight, the results are summed. For each alternative, the overall utility is 2.7 and 9.3 respectively for “during design”, and 6.2 and 5.8 for “during construction”. The final columns of Table 10.10 show cost-utility ratios that were derived by dividing the cost by the appropriate utility score. The lowest CU ratios imply the lowest cost for obtaining a given level of utility, and the highest CU ratios imply the highest cost. On this basis, the cost to utility ratio of Function E is \$2,258 for “during design”, and \$3,620 for “during construction,” and it appears to be more preferable than a traditional paper-based document delivery approach. As shown in Table 10.10, the biggest savings comes from reduction in turn-around times and search times. Ubiquitous data accessibility, error reduction, and up-to-date information is another benefit of Function E.

10.7.3 Summary

1) Function E provides opportunity to save plan printing & delivering cost and speed up the turnaround time associated with plan and spec revisions.

2) As is noted in Table 10.10, Function E is less expensive in terms of costs. Furthermore, cost effectiveness analysis demonstrates that Function E is more cost effective than the other with respect to the designated measures of effectiveness.

3) Finally, when erecting steel components, a foreman spends a lot of moving time to and from a trailer office to read a plan and document. Function E can help in reducing this waste.

11. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

This chapter will present the summary of this study followed by a discussion of the accomplished objectives, conclusions, and recommendations for future work.

11.1 Summary

The construction industry suffers from stagnant productivity, a high accident rate, project delays, and quality problems. Research studies have shown that the major cause of these performance problems can be traced back to the lack of effective communication among construction process units, a situation commonly referred to as “islands of communication.”

The goal of this research project was to investigate the feasibility, functionality, and value of an agent-mediated communication concept. In order to test, validate, and assess key components of the concept, a prototype Wi-Fi agent system was developed and tested on an industrial construction project.

In a first step, relevant literature was reviewed to establish the state-of-the-art in the area of wireless agent communication. The impact of a construction site full of machinery on long-haul wireless links had to be investigated first. In addition, a wireless weather station was pre-tested. This system included various solar-powered sensors to measure indoor and outdoor temperature, rainfall, wind speed/direction, and humidity.

Due to security issues, the adoption of a new University's policy on installation of Wi-Fi devices, and a need for a reliable interface, it was decided to replace the long-haul communication link with a wired connection. A Chilled Water Plant Project ready to be built on NCSU campus was selected as the testing ground for the experimental system. After a site survey, the locations for installing the weather sensors, two video cameras, two access points, and one repeater were determined.

The two main efforts of this thesis included the assessment of Wi-Fi technologies and the applicability of ubiquitous agent technologies. As a first step, the survey was organized to learn about the current state-of-practice and explore opportunities of Wi-Fi enabled agent applications in the U.S. construction industries.

Before the installation of the Wi-Fi hardware, building access permits to the roof of Carmichael Gymnasium were approved by University and site access from the Gilbane Building company were secured. In collaboration with the University's computer networking group, two wireless backbone networks were deployed, one inside the Carmichael Gymnasium, the other inside the existing Cates Heating Plant. After setup, environmental effects on the Wi-Fi signal strength and throughput were measured.

Integrating three network cameras, an ICS & Web server, two access points, one repeater, two antennas, and four sensors presented numerous challenges. The necessary trial-and-error approach to find workable solutions consumed large amounts of time. Parallel to the established backbone network, two configurations of a crane alert agent were deployed as examples of machine-to-machine (M2M) communications.

Subsequently, a multi-media human-to-human (H2H) augmentation system was established. Eventually, the Wi-Fi agent system supported the following five functions: 1) Crane alert agent, 2) ubiquitous site inspection, 3) ubiquitous problem solving, 4) ubiquitous sensing and data access, and 5) e-Document Management.

Field experiments provided both qualitative and quantitative data about the functionality and effectiveness of the five functions. The list of conducted final system tests included: 1) a Wi-Fi site signal test, 2) a ping test, 3) an agent interoperability test, and 4) a camera turn-on time test. During steel erection of the plant, various data sets were collected: 1) RFI turnaround times, 2) submittal turnaround times, 3) productivity ratings, and 4) continuous time study.

The project ended with an effort to establish the values of the five agent functions using several value assessment methods. In order to come to broad-based conclusions, multiple methods were employed to evaluate the same functions. Furthermore, the results from the survey were used to support the validity of the value analysis.

The following section will provide a quick discussion of the accomplished objectives.

11.2 Discussion of Objective Accomplishments

This section follows the six research objectives established in section 1.6.

11.2.1 The Objective 1:

Evaluate key communication channels and current State-of-Practice tools in construction.

An extensive literature review was conducted to establish the state-of-art in communication technologies. A limited industry survey was organized to establish a basic understanding of the state-of-practice.

11.2.2 The Objective 2:

Study and model material and information flow for structural steel construction processes to establish a data need and analysis of critical communication problems.

A Chilled Water Plant Project at NCSU campus served as the test ground to investigate steel construction. The study included a visit to the contractor's steel plant in Asheville, NC, review of plan (design, fabrication, and erection), field observations and studies. Subsequently, steel and information flows were modeled.

11.2.3 The Objective 3:

Develop a prototype neutral data format for structural steel construction processes.

In addition to developing a neutral data format for steel construction, an off-the-shelf weather agent system was used to create a prototype wireless crane alert function.

11.2.4 The Objective 4:

Develop and implement Wi-Fi agent system to support real-time and interactive information sharing among process units.

The development of the Wi-Fi system for the Chilled Water Plant had to consider many constraints both physical and regulatory. Eventually a working system with two backbones and several communication agents was installed and tested. Signal throughput and functionality of a variety of tools were assessed during field operations.

11.2.5 The Objective 5:

Collect and analyze performance data to determine the functionality, reliability, and associated effects of Wi-Fi agent system.

As expected, the restrictive site conditions and equipment noise created a challenge for keeping the Wi-Fi agent system optimized at all times. Before, during, and after the steel erection process, data about throughput and speed was collected, analyzed, and used to modify the system as needed. Many lessons about the effects of the construction on Wi-Fi system were learned.

11.2.6 The Objective 6:

Assess the overall economic effects of Wi-Fi agent system.

In order to limit the scope of study, five agent functions were selected for the assessment of value. For each function, data was collected and used to appraise the value using six different evaluation methods

The conclusions drawn from the project work are presented in the next section.

11.3 Conclusions

The conclusions are organized according to the four research hypotheses established in section 1.5.

11.3.1 The First Hypothesis:

On construction sites, manmade obstacles and various types of equipment and machinery can significantly degrade the performance of a wireless network, restricting operating range and data throughput.

The field experiments highlighted the importance of reliable wireless connection and power supply in a environment full of man-made obstacles, machinery, and equipment.

1) It was confirmed that signal attenuation is strongly impacted by the surrounding environment such as brick walls, solid metal doors (inside Carmichael Gymnasium), thin insulated metal walls (Cates Plant), and steel beams/columns of the structure under construction. In a large indoor space, the signal strength (41 [low] ~ 47 % [high] and

link quality 88~96%) is sufficient, but will not pass through the building envelope. This shortcoming can be overcome by installing repeaters at appropriate places.

The results of signal measurements for different configurations of Wi-Fi networks demonstrated that the main reason causing loss of connectivity and reducing radio signal strength is the presence of solid concrete walls or metal. Similarly, brick walls can create conditions that stop any radio signal of 2.4 GHz, used in wireless technologies, from getting through. It was confirmed that even smaller manmade obstacles (e.g., columns/beams) significantly degrade the performance of wireless networks, restricting operating range and data throughput.

2) Measurements conducted on two consecutive days, with and without operating equipment, showed that link quality on a working day varies much more widely than during a non-working day. This results in the reduction of data throughput in the laydown area. A contractor has to be aware that construction machines and equipment degrade the performance of wireless networks, restricting operating range and data throughput.

3) Wireless devices require power. Due to the lack of available electrical power on the roof of the Carmichael building, where the wireless SONY wireless cameras had to be placed, a solar power package had to be built. It consisted of : 1) Car battery, 2) 6 Watt solar panel, 3) 2 Watt solar panel, 4) a solar charger controller, and 5) a power control kit. During the test operation, it was observed that the camera turn-on time varied from 3 to 8

hours depending on clouds during the day. Another problem was the fact that the camera had no remote turn-off capability, thus the battery drained during the night.

4) Omni-directional outdoor antennas provide wide coverage, but adjacent networks are likely to interfere. Directional antennas with varied fields of coverage have been found most suitable for construction sites. The beam angle of the directional antenna may need to be realigned according to the changing site conditions.

The study reinforces the need for careful planning before building a Wi-Fi system for construction. It is very imperative to identify an acceptable data rate, signal strength, signal quality, and optimum number and locations of access points before installing a wireless network. In addition, co-channel interference and security problems have to be paid close attention. It seems that it might be effective to consider a strategy in which wireless network is built into the structure and powered by temporary power cords.

11.3.2 The Second Hypothesis:

A multi-media IP-enabled communication can let technical experts in the office provide real time guidance and assistance to field personnel.

The experimental testing of the five agent functions supported the second hypothesis. In fact, the thrust of the hypothesis was found to be very narrow because the H2H configuration used by field personnel either on or off site is able to provide even

greater opportunities to create value. Four IP-enabled applications were tested: 1) Remote inspection, 2) collaborative problem solving, 3) work front data access, 4) operator augmentation.

1) Remote inspection: This function enables qualified personnel access to the site through a multi-media link. The results presented in chapter 9.6 support the technical feasibility of conducting remote visual inspection using fixed and mobile video cameras. The utilization of wireless cameras within the range of a Wi-Fi site network allows an inspector (e.g., safety) situated in the main office to view but also to interact with site personnel using video and/or audio. Furthermore, such an application provides innumerable opportunities to document the operation and the process of the project, thus creating automatically a media rich as-built document.

2) Collaborative problem solving: The outcome of field experiments in chapter 9.6 shows that a site Wi-Fi network is able to provide moderate quality audio and video from the jobsite. Internet phone tests revealed that incompatible hardware is still an existing problem. This shortcoming could be overcome by using cell phones.

3) Work front data access: Wi-Fi communication is a key enabling tool to allow workers to access to the Internet (e.g., e-Document). In an H2M scenario, retrieving up-to-date CAD drawings by the steel foreman standing at the work front will provide many valuable benefits. For example, the time spent searching for a detailed drawing in a set of

blue prints will be eliminated through the use of hyper-linked CAD drawings displayed on a large sized flat touch screen. Other features that are supported by such an capability are a long list of e-Document management functions.

4) Operator augmentation: Connecting the operator sitting in the crane cabin to remote “islands” augmented his ability to perform his job more safely and efficiently. By mounting a small wireless camera with audio capability on a ground worker’s hardhat, the operator gained an additional set of “eyes” and “ears” to ensure the safety of the load (e.g., steel beam properly hooked). The operator is able to interact with anybody wearing such a helmet, making him connected to many “islands”.

11.3.3 The Third Hypothesis:

An Information Agent-Mediated Communication model (IAMC) provides an efficient platform for M2M (Machine to Machine) interaction under wireless construction environments. As a core requirement for agent communication, neutral agent ontology will help in offering interoperability between incompatible agent systems.

The observations related to this hypothesis were made while testing the crane alert and SONY camera agents. Factors that affect the effectiveness of an IAMC platform can be organized into five categories: 1) Autonomy, 2) data consistency, 3) network speed, 4) connectivity, and 5) compatibility. The following briefly addresses each of them.

1) Autonomy: The crane alert agent was designed to operate autonomously for twenty four hours a day. Its multifunctional structure was built on top of two wireless networks. One linked five solar powered sensors that communicated at 433 MHz with the data storage and relay module interfaced with the weather server (PC). The second, a 802.11b Wi-Fi LAN, linked the weather server with the crane. Those two networks were “chained” via the PC programmed to operate as a server agent to the crane as well as to the Internet. New client agents were easily added by appending new e-mail to its list to send messages when a “danger” levels was passed (e.g., wind speed of 20 miles per hour). At the same token, on-site client agents received a warning, triggering emergency devices such as audible horns and/or flashing lights.

Similarly, a FTP server on the PC automatically stored images from the SONY camera.

2) Data consistency: The M2M agent-mediated communication network was used to connect the weather sensors, weather agents, Web server, ICS server, FTP server, LAN, and Internet. The data format coded into the weather station created the necessary consistency between the main components of the crane alert system. Data sharing between server and client agents resulted in matching data sets on both.

3) Network speed: As anticipated, a push-based alert agent network using only the wireless LANs was slightly faster than a pull-based configuration using both the Internet and Wi-Fi. Both provided acceptable response times for text data used by the weather

agents. The agents also had two channels for accessing a remote data server, FTP and HTTP. While responses are different slightly, either channel allows for sufficient data download used by the weather agents. On the other hand, the SONY agent used JPG image (15 kbps), resulting in a slow down of frame rate per second. As consequence, it is important to define needed service (e.g., frame rate) before designing a Wi-Fi backbone.

4) Connectivity: As the weather agents were programmed to communicate in either FTP or HTTP format, it allowed them to easily connect to various nation-wide weather servers including the RDU airport META data readings. On-site connectivity was created by the 802.11b standard. Since all commercial wireless devices use the same standard, connectivity is easily guaranteed.

5) Compatibility: As with connectivity, standards are critical for achieving compatibility. The Wireless Ethernet Compatibility Alliance¹ (WECA) certifies 802.11b products and attaches the Wi-Fi logo to ensure that the products with the logo are interoperable each other. For example, the Cisco wireless adapter and the D-link router/repeater are compatible to allow SONY camera to send video image to the FTP server through Wi-Fi network. However, the weather agents not Wi-Fi certified could be not interoperable with the Cisco or D-link wireless devices. This barrier was circumvented using a PC/LAN interface.

Presently, interfaces have to be built to bridge the different Wi-Fi channels and devices. Furthermore, a client and server architecture (i.e., hub and spoke) adopted in this study will become an ineffective approach if the number of servers and clients increases. It is envisioned that this will give rise to peer-to-peer mesh network.

11.3.4 The Fourth Hypothesis:

By connecting today's "islands of information", Wi-Fi agent functions offer a diverse set of opportunities to create new value.

Every successful technology intends to improve the lives of people. In the world of construction, such improvements may focus on safety, quality, and productivity. The five selected Wi-Fi agent functions are evaluated based on this basic principle.

1) Crane alert: The value of the crane alert function lies in reducing the risk of a crane accident due to wind. Its capability to warn a crane operator against an impending wind-related hazard, allows for the time necessary to move the crane to a safe position.

2) Ubiquitous site inspection: The multiple applications of this scheme will reduce inspection costs and increase the efficiency of the inspectors while creating many new benefits due to 24/7 remote access to the site as well as to an ever increasing number of IP-based sensing platforms.

3) Ubiquitous problem solving: Common problems during construction and inspection are unclear or erroneous design drawings (requiring RFIs). A wireless multi-media Web environment will allow for “near-real-time” problem solving, thus eliminating most RFIs and their associated cost.

4) Ubiquitous sensing and data access: Wi-Fi or PCS Cellular-enabled sensing devices enable remote equipment monitoring and site measurement. It makes the collected data available real time while creating records and documents for future use or reference.

5) e-Document management: Much time and money is spent because of the paper-based exchange of drawings and documents. e-Document management creates many opportunities to improve the presently wasteful methods not only during design, but also construction and operation. Time spent for shipping, searching, error-tracking, and printing will be significantly reduced. Installing a wireless smart display station at the work front will provide workers easy access to any relevant information at the place of work. Instant and updated information is offered by efficient search engines. This information portal at the work place promises large gains in productivity and quality of construction.

11.4 Recommendations for Future Work

The following section outlines potential future research implied by this research.

Construction of Shared Domain of Ontologies:

The scope of this dissertation was limited to the examination of information agents. However, this is not enough to maintain a multi-agent system (MAS) capable of accomplishing complex tasks by coordination of an individual agent application without human guidance or intervention. As an important first step to building the prototype multi-agent systems (MAS) for structural steel construction, a shared domain of ontologies needs to be developed.

Management of Wi-Fi RF Interference:

The comparative experiment showed that there is the presence of RF interference from construction equipment. Even without this construction equipment, a connection was sometimes unstable, significantly reducing the throughput. It is assumed that there is a possibility that our wireless system can experience interference from others wireless networks set to the same or adjacent channel. During the field test, several other wireless LANs was detected. Detail performance problems due to co-channel and adjacent channel interference should be identified and their sources characterized.

Management of Conflicting Values:

The value assessment of Wi-Fi agent functions was conducted, independently without considering its impact on other interrelated functions. However, value conflict between interrelated functions in decision making is usually inevitable, particularly when

monetary or economic values are involved. To create the highest levels of “win-win” outcomes, the impact of conflicting values on other interconnected functions needs to be considered.

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Appendix A

Survey Form for Current Communication Technologies

Background Information:			
1. What is the core business of the company that you work for?			
2. What is your position within the company?			
3. In what area of the US does your company perform most of its work?			
4. What was the approximate total "sales" in 2004?			
5. Does the company have:		Yes	No
	- a Web site?		
	- computers on site?		
	- Internet access in field offices?		

Present Use of Communication Technologies:			
1. What information channels do you rely on for your work to request information, clarifications, or confirmations? (Please enter a 0 = never, 1 = hardly ever, 2 = sometimes, or 3 = a lot into the appropriate box)			
Regular phone		E-mail	
Cell-Phone		Fax	
Two-Way Radio		Face-to-Face (one-on-one)	
		Team-meetings	
		Express Mail (UPS, FEDEX...)	
		Other	
2. What information channel are you using for your work to distribute information, orders or respond to queries? (Please enter a 0 = never, 1 = hardly ever, 2 = sometimes, or 3 = a lot into the appropriate box)			
Regular phone		E-mail	
Cell-Phone		Fax	
Two-Way Radio		Face-to-Face (one-on-one)	
		Team-meetings	
		Express Mail (UPS, FEDEX...)	
		Other	
3. What digital tools are you using for your work? (Please enter a 0 = never, 1 = hardly ever, 2 = sometimes, or 3 = a lot into the appropriate box)			
Still Camera		PDA (Personal Digital Assistant)	
Phone		Laptops	
Video-Camera		Desktop PCs	
		Tablet PCs	
		Electronic Sensors	
		Other	

Appendix A (continued)

4. What of the following cutting edge computer tools and means do you use?
(Please enter a 0 = never, 1 = hardly ever, 2 = sometimes, or 3 = a lot into the appropriate box)

GIS		RFID		Construction Web-Portals	
GPS		eBid		Video-conferencing	
CAD (2-D, 3-D, 4-D)		eLearning		Other	
E-commerce (eBuying)		Barcode Scanning		Other	

5. Does your company use any of the following wireless technologies: (Please check P all that apply)

Wireless network in main office		Wireless equipment/material yard	
Long-haul wireless (from office to remote site)		Wireless surveillance cameras	
Wireless network on construction site		Other	

6. If wireless communication technology (in addition to cell-phones) is in use by your company, have you or your company seen improvements in any of the following areas: (Please check all that apply)

Productivity		Overhead cost		“Production” cost	
Service (speed, reliability)		Labor Management		Availability of data/information	
Security		Work flexibility		Other	
Equip/Mat Management		Time wasted			

Opportunities for Web-Based Communication in Construction:

Assign a number between 0 - 3 to indicate what capability from the list below would provide real benefits/ value to you or your company: (Please enter a 0 = not at all, 1 = minor, 2 = some, or 3 = a lot/major)

- send and receive design/shop drawings electronically		- provide real time information to anybody on site (i.e., CAD, safety rules, material location)	
- receive design approvals electronically		- training of crews, foremen, and managers	
- monitor the construction site 24/7 on the computer screen or pocket PC		- provide real-time collaboration between project participants (video and audio)	

Appendix A (continued)

- obtain automatic records of temperature, humidity, wind, etc. in- and outside		- provide the owner with a visual “as-it-was-built” documentation including visual inspections	
- record automatically 3 minute time-lapse movie of an entire work day		- having a 24/7 “security fence” with automatic monitoring/capturing system	
- establish an automatic record of information exchange between project participants		- replace weekly site meetings with real-time Web-postings and video-conferencing	
- receive real-time status information about material supply trucks + load (e.g., steel)		Others	
- to monitor the implementation of safety rules including recording perfect conditions			

Barriers to the use of Web-Based Communication in Construction:

Indicate by assigning a value between 0-3 the severity of barriers that inhibit the implementation and use of Web-based communication technologies in construction (not restricted to your company):

I feel that an important barrier is: (Please enter a 0 = not an issue, 1 = minor, 2 = some, or 3 = a lot/major)

- high cost and little return on investment		- incentives for personnel to participate	
- needed training		- creates more work for people	
- lack of knowledgeable personnel to support its implementation and long term support		- lack of collaboration in the business we are in	
- lack of data security and virus threat		- lack of metrics to assess its value	
- risk of system failure and loss of data		- unclear benefits for individuals & company	
- Other		- Other	

Barriers to the use of Wireless Technologies in Construction:

If your company does NOT use wireless technologies (with the exception of cell phones) what are some of the main reasons: (Please check all that apply)

Lack of security		Cost of networking / telecommunications	
Lack of industry standards and infrastructure		Lack of expertise in wireless use in construction	
Lack of appropriate laws and regulations		Other	

Appendix B

Actual Data Throughputs

Count of Observation	D-link (DWL 1000)	Panasonic	SONY (SNC-30ZN)	Total Data Rate (Kbps)
1	464	857	2636	3957
2	452	906	2613	3971
3	520	802	2507	3829
4	464	912	2247	3623
5	465	624	2568	3657
6	272	926	2587	3785
7	486	897	2621	4004
8	570	937	2520	4027
9	428	877	2649	3954
10	554	906	2573	4033
11	575	895	2666	4136
12	337	921	2555	3813
13	273	927	2627	3827
14	514	873	2454	3841
15	453	926	2563	3942
16	467	896	2162	3525
17	454	767	2350	3571
18	545	871	2444	3860
19	531	755	2634	3920
20	468	906	2184	3558
21	589	872	2609	4070
22	531	709	2674	3914
23	469	906	2537	3912
24	453	908	2588	3949
25	513	861	2535	3909
Max				4136
Link Quality Condition	100%	100%	100%	
Signal Strength Condition	95~100%	95~100%	90~95%	

Appendix C

Data Rates and Signal Readings

Wireless Site Survey							
Access point	D-link 810					Weather	Clear
						Date	4/21/2005
Location	Ground Level					Time	2:00pm
Point Stride Number	Location Distance	Link Quality (%)		Signal Strength (%)		Transmission Rate (Mbps)	
		Low	High	Low	High		
1	0 ft	48	90	10	39	11	
2	38ft	0	84	0	33	0	
3	75 ft	50	98	21	37	11	
4	113 ft	55	100	37	40	22	
5	138 ft	58	88	31	40	22	
6	175 ft	58	100	42	46	22	
7	233 ft	98	100	43	45	22	

Wireless Site Survey (on Working Day)							
Access point	D-link 900					Weather	Clear
						Date	4/21/2005
Location	Ground Level					Time	3:00pm
Point Stride Number	Location Distance	Link Quality (%)		Signal Strength (%)		Transmission Rate (Mbps)	
		Low	High	Low	High		
1	0 ft	62	80	46	53	22	
2	38ft	43	64	57	61	22	
3	75 ft	64	86	49	54	22	
4	113 ft	48	82	49	58	22	
5	138 ft	45	100	43	48	11	
6	175 ft	66	100	38	46	11	
7	233 ft	54	100	19	34	2	

Wireless Site Survey (on Holiday)							
Access point	D-link 900					Weather	Clear
						Date	4/16/2005
Location	Ground Level					Time	3:00pm
Point Stride Number	Location Distance	Link Quality (%)		Signal Strength (%)		Transmission Rate (Mbps)	
		Low	High	Low	High		
1	0 ft	48	64	55	59	22	
2	38ft	65	78	55	63	22	
3	75 ft	73	80	62	65	22	
4	113 ft	68	84	51	56	22	
5	138 ft	54	67	44	47	22	
6	175 ft	60	72	44	50	22	
7	233 ft	51	67	41	44	11	

Appendix D

Ping Test Statistics Results

Number	Weather client to D-link access point (IP address 192.168.0.50)				Weather client to Weather server (192.168.0.1)				Weather client to NCSU FTP server (ftp.ncsu.edu)			
	A	B	C	D	A	B	C	D	A	B	C	D
1	0	10	2	0	0	10	2	25	0	10	2	25
2	0	10	2	0	0	0	0	0	0	10	5	0
3	0	0	0	25	0	10	2	25	0	10	2	50
4	0	10	2	0	0	10	2	0	0	10	2	0
5	0	0	0	0	0	10	2	0	0	10	2	25
6	0	10	2	0	0	10	2	0	0	10	5	0
7	0	0	0	0	0	10	2	0	0	10	7	0
8	0	10	2	0	0	10	2	0	0	0	0	0
9	0	10	2	0	0	0	0	0	0	10	5	0
10	0	10	2	0	0	10	2	0	0	10	5	0
Average	0	7	1.4	2.5	0	8	1.6	5	0	9	3.5	10

A: Minimum (ms: Mili second) B: Maximum (ms) C: Average (ms) D: Packets Loss (%)

Appendix E

RFIs Log & Submittals Turnaround Time

(RFIs Log)

Sender	Receiver	Number of RFIs cases
Gilbane Building Company	RMF Engineering, Inc	229
Gilbane Building Company	Gilbane Building Company	3
Gilbane Building Company	Dave Steel Company	1
Gilbane Building Company	BBH Design	1
Dave Steel Company	John J. Kirlin, Inc.	1
Dave Steel Company	RMF Engineering, Inc.	3
Acorn Industrial	Gilbane Building Company	1
T & H Electrical Corporation	RMF Engineering, Inc.	1
Ivey Mechanical Company	RMF Engineering, Inc.	1

(Submittals Turnaround Time)

Description	Turnaround Time (Day)
Structural Steel - Typical Details	10
Steel Joist	7
Steel Deck	20
Structural Steel - Anchor Bolt and Embed Shop Drawing	11
Structural Steel - Sequence 1 & 2 Calcs, Shop Drawings	28
Structural Steel - Sequence 3 & 4 Shop Drawings	22
Structural Steel - Sequence 5 & 6 Shop Drawings	24
Structural Steel-PE Stamped Letter	14
Structural Steel - Qualifications and Welder Certificates	13
Structural Steel - Harris Erector Weld Certs	11
Structural Steel - Bolts All Sequences, Steel Sequence 1	13
Steel Joist	11
Steel Deck	11

Appendix F

Descriptions of the Data Dictionary

Class Name	Data Element	Definition	Type of Data	Unit of measurement	Data Resolution	Data Format	Data Length
Structural steel number information	Identification number	product identity number to help identify members on the jobsite	text	N/A	1	YYYY	4
	Section number	order in which a zone or section of the structural steel frame will be erected	text	N/A	1	YY	2
	Load number	number of a group of steel components delivered by the truck	text	N/A	1	Y	1
	Sequence number	sequence in which parts and assemblies are to be assembled during erection to create the final structure	text	N/A	1	YY	
Physical characteristics	Weight	one of physical characteristics of the structural steel component	number	ton	1	YY	2
	Length	one of physical characteristics of the structural steel component	number	ft	0.01	YY.YY	5
	Center of gravity	one of physical characteristics of the structural steel component	number	ft	0.01	YY.YY	5
Erection characteristics	Identification number	product identity number to help identify members on the jobsite	text	N/A	1	YYYY	4
	Orientation mark	orientation in which parts and assemblies are to be assembled during erection to create the final structure	text	N/A	N/A	Y	N/A

Appendix F (continued)

	Position drawing	drawing with which parts and assemblies are to be positioned during erection to create the final structure	Drawing	N/A	N/A	N/A	N/A
Delivery request	Section number	order in which a zone or section of the structural steel frame will be erected	text	N/A	1	YY	2
	Field need date	date which steel erector ask materials to be delivered to the jobsite	Date/time	dd-mm-yy	1	N/A	8
	Factory delivery date	date which steel fabricator expects materials to be delivered to the jobsite	Date/time	dd-mm-yy	1	N/A	8
Erection status	Identification number	product identity number to help identify members on the jobsite	text	N/A	1	YYYY	4
	Erection start	date which steel erector start to erect steel components at the jobsite	Date/time	dd-mm-yy	1	N/A	8
	Erection completed	date which steel erector finish to erect steel components at the jobsite	Date/time	dd-mm-yy	1	N/A	8
Fabrication status	Section number	order in which a zone or section of the structural steel frame will be erected	text	N/A	1	YY	2
	Fabrication start	date which steel fabricator start to fabricate steel components at the factory	Date/time	dd-mm-yy	1	N/A	8
	Fabrication completed	date which steel fabricator finish to fabricate steel components at the factory	Date/time	dd-mm-yy	1	N/A	8

Appendix F (continued)

Shop drawing status	Section number	order in which a zone or section of the structural steel frame will be erected	text	N/A	1	YY	2
	Submit for approval	date which steel fabricator submit shop drawing for approval to engineers	Date/time	dd-mm-yy	1	N/A	8
	Approval return	date which shop drawing is returned to steel fabricator after approval	Date/time	dd-mm-yy	1	N/A	8
Delivery status	Load number	number of a group of steel components delivered by the truck	text	N/A	1	Y	1
	Delivery start	date which steel fabricator start to deliver steel components at the factory	Date/time	dd-mm-yy	1	N/A	8
	Delivery completed	date which steel fabricator finish to deliver steel components at the factory	Date/time	dd-mm-yy	1	N/A	8
RFID	Identification number	product identity number to help identify members on the jobsite	text	N/A	1	YYYY	4

Appendix G

Descriptions of Class Name

Class	Description
Structural steel number information	This class represents the data which indicate the order in which a zone or section of the structural steel frame will be erected.
	This class also represents the data which show sequence in which these parts and assemblies are to be assembled during erection to create the final structure.
	This class also shows the number which identifies the unique steel component.
	This class also shows the data which shows the load number of a group of steel components delivered by the truck.
Physical characteristics	This class represents all data which shows the physical characteristics (weight, length, and center of gravity) of the structural steel component. It also shows product identity to help identify members on the jobsite.
Erection characteristics	This class represents the data which shows the positions and orientations of all the pieces in their final locations.
Delivery request	This class represents the data which shows when steel erector need materials and until when they can be delivered to the jobsite by steel fabricator.
Erection status	This class is the data which shows the erection status of the steel component in the worksite.
Fabrication status	This class is the data which shows the fabrication status of the steel component in the factory.
Shop drawing status	This class is the data which shows the shop-drawing approval status between project participants.
Delivery status	This class is the data which shows the delivery status of the steel component in the worksite.
RFID	This class represents all data which shows the identification number interrogated through RFID sensor.