NUNTASUNTI, SUCHART. The Effects of Visual-Based Information Logistics in Construction. (Under the direction of Leonhard E. Bernold.)

The construction industry has, for sometime, suffered from stagnant productivity, high accident rate, project delays, and poor quality. Research studies have shown that the major cause of these performance problems is the lack of effective communication. This research was launched to investigate the usefulness of a comprehensive information logistics model on construction process performance. In order to test and validate key components of the model, a prototype network system named Visual-based Integrated Wireless Site (V-IWS) was developed and tested on a mid-size building construction project. The system was designed to allow every project participant access to real-time visual images of the jobsite and share information interactively with each other as well as with a central database through the Internet. It was developed and evaluated for 7 months in 2003. During the same time, the communication channels adopted by the general contractor, R.N. Rouse, and on-site meetings were observed and analyzed. This analysis indicated that most of the information shared among participants of this project could be handled electronically by the V-IWS. It was demonstrated that the V-IWS: a) reduces production waste and non value-added activities such as material delivery time, b) eliminate the need for unnecessary site visits and meetings, c) adds significant value to project participants by automatically creating visual as-built and picture archives, d) provides operational how-to training for crew, and e) increases site safety and security.
through automated monitoring. The system is scaleable and more network devices can be added as the building grows. While this study proved technical feasibility of the V-IWS, it became evident that trust, collaboration and information sharing among participants were critical success factors. Due to the industry’s traditional low-bid competition and aversion to change, it is crucial to understand how costs and benefits be distributed. Value sharing as well as technology adoption process need to be studied in order to ensure successful implementation of the system.
BIOGRAPHY

Suchart Nuntasunti was born in Thailand, on September 24, 1966. He received the degree of Bachelor of Engineering in Civil Engineering from Chulalongkorn University, Bangkok, in 1989. He worked with leading construction companies in Bangkok from 1989 to 1998. During that time he was involved in more than ten high-rise building projects. He received the degree of Master of Engineering in Construction Management from Chulalongkorn University in 1996. He served as assistant secretary and sub-committee member on construction management of the Engineering Institute of Thailand under H.M. the King’s Patronage (EIT) from 1996 to 1999. He also was the co-author of “Method of Measurement Guide for Building Work (Structural and Architectural),” EIT, Jan 1997.
ACKNOWLEDGEMENTS

This research is sponsored by the National Science Foundation (NSF) under Grant No. CMS 0080073.

I would like to express gratitude and appreciation to my advisor, Dr. Leonhard E. Bernold, for his guidance, encouragement and mentoring. To my committee members: Dr. William J. Rasdorf, Dr. Robert E. Young, and Dr. Duncan M. Holthausen, I extend my appreciation for their valuable input into my research. Permissions from Spectrum Home Inc. and R.N. Rouse & Co., Inc. to collect invaluable data are gratefully acknowledged. Thanks to Mr. Allen from NC State Information Technology/Computing Services for his guidance in setting up wireless network. To Chanchai, Lijuan and all my friends in the Construction Automation and Robotics Laboratory (CARL), I thank you for your help and support.

Finally, special thanks to my parents and my wife Malee, for their love, support and understanding.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>LIST OF TABLES</td>
<td>viii</td>
</tr>
<tr>
<td>LIST OF FIGURES</td>
<td>ix</td>
</tr>
<tr>
<td>1. INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>1.1. Performance Review of the Construction Industry</td>
<td>1</td>
</tr>
<tr>
<td>1.2. Low Performance Caused by Asynchronous Information</td>
<td>3</td>
</tr>
<tr>
<td>1.3. Problem Statement and Need</td>
<td>6</td>
</tr>
<tr>
<td>1.4. Research Objectives</td>
<td>8</td>
</tr>
<tr>
<td>1.5. Organization of the Thesis</td>
<td>9</td>
</tr>
<tr>
<td>2. LITERATURE REVIEW</td>
<td>10</td>
</tr>
<tr>
<td>2.1. Construction Process Review</td>
<td>10</td>
</tr>
<tr>
<td>2.1.1. Resources as Process inputs</td>
<td>11</td>
</tr>
<tr>
<td>2.1.2. Recognition of Information as a Resource</td>
<td>13</td>
</tr>
<tr>
<td>2.1.3. Activity Planning versus Process Planning</td>
<td>14</td>
</tr>
<tr>
<td>2.2. Communication in Construction Project</td>
<td>16</td>
</tr>
<tr>
<td>2.3. Information Logistics</td>
<td>19</td>
</tr>
<tr>
<td>2.4. Waste Concepts Based-on Lean Thinking</td>
<td>23</td>
</tr>
<tr>
<td>2.5. Information Technologies</td>
<td>27</td>
</tr>
</tbody>
</table>
2.5.1. MRP II, ERP, and CERP ........................................... 27
2.5.2. Network, the Internet and TCP/IP Protocols ...................... 31
2.5.3. Wi-Fi .............................................................. 35
2.6. IT Implementation in Construction ................................... 37
2.7. Summary of Problems and Issues ..................................... 39

3. INTEGRATED WIRELESS SITE (IWS) ................................. 41
3.1. Information Logistics for Construction ................................ 41
3.2. Integrated Wireless Site (IWS) ........................................ 45
3.3. Conceptual Framework and Uses ...................................... 48
3.4. IWS as a Tool for Adding Team’s Value .............................. 52
  3.4.1. Extended Construction Waste Concepts Based on
         Lean Thinking ......................................................... 53
  3.4.2. Creating New Value ............................................... 58
3.5. Collaborative and Share: A Win-Win Situation ..................... 60

4. DEVELOPMENT OF VISUAL-BASED IWS SYSTEM (V-IWS) .... 64
4.1. Effectiveness of Visualization ......................................... 64
4.2. Sources of Visual Based Information ................................ 65
  4.2.1. Public Database and Outsourcing ................................. 65
  4.2.2. Still Digital Photo and Video Clip ................................ 68
  4.2.3. Disadvantages of Using Video and Digital Still Camera ...... 73
4.3. V-IWS System Design ................................................ 73
  4.3.1. System Components ............................................... 74
  4.3.2. Regulation and Security Consideration ........................ 77
6.4.2. System Benefits ....................................................... 123
6.4.3. Cost Benefit Comparisons ....................................... 126

7. CONCLUSION AND FUTURE WORK .................................... 130
  7.1. Summary ..................................................................... 130
  7.2. Conclusion ................................................................... 132
  7.3. Recommendation for Future Research ............................ 140

LIST OF REFERENCES ........................................................... 142
APPENDIX A FCC Regulation on Wireless Communication .......... 151
APPENDIX B NCSU Policy on Wireless Communication ............... 159
APPENDIX C Sample of ASP Code ....................................... 164
APPENDIX D Sample of Signal Strength and Quality Data ............ 170
APPENDIX E Information Flow Analysis Form .......................... 173
APPENDIX F Value Assessment Survey Form ......................... 175
## LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table 1.1</td>
<td>Foremen’s main source of delay</td>
<td>4</td>
</tr>
<tr>
<td>Table 2.1</td>
<td>Approved 802.11x standards</td>
<td>35</td>
</tr>
<tr>
<td>Table 2.2</td>
<td>WLAN costs/benefits study</td>
<td>36</td>
</tr>
<tr>
<td>Table 6.1</td>
<td>Information code description</td>
<td>102</td>
</tr>
<tr>
<td>Table 6.2</td>
<td>Messages classified by functions</td>
<td>105</td>
</tr>
</tbody>
</table>
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 2.1</td>
<td>Transformation concept of production</td>
<td>11</td>
</tr>
<tr>
<td>Figure 2.2</td>
<td>Input/output process model</td>
<td>12</td>
</tr>
<tr>
<td>Figure 2.3</td>
<td>Materials and associated information flow in construction project</td>
<td>14</td>
</tr>
<tr>
<td>Figure 2.4</td>
<td>Information flow diagram</td>
<td>17</td>
</tr>
<tr>
<td>Figure 2.5</td>
<td>Communication flow in a construction alliance</td>
<td>18</td>
</tr>
<tr>
<td>Figure 2.6</td>
<td>Physical logistics network</td>
<td>20</td>
</tr>
<tr>
<td>Figure 2.7</td>
<td>Logistics life cycle</td>
<td>22</td>
</tr>
<tr>
<td>Figure 2.8</td>
<td>Conceptual CERP architecture</td>
<td>29</td>
</tr>
<tr>
<td>Figure 2.9</td>
<td>IP address classes</td>
<td>33</td>
</tr>
<tr>
<td>Figure 2.10</td>
<td>#1 investment priorities for corporate executives, project managers and information technologists</td>
<td>38</td>
</tr>
<tr>
<td>Figure 3.1</td>
<td>ILC flow model</td>
<td>42</td>
</tr>
<tr>
<td>Figure 3.2</td>
<td>Information flow in horizontal and vertical directions</td>
<td>44</td>
</tr>
<tr>
<td>Figure 3.3</td>
<td>Information flow structure of IWS</td>
<td>46</td>
</tr>
<tr>
<td>Figure 3.4</td>
<td>Extended functional breakdown of construction</td>
<td>47</td>
</tr>
<tr>
<td>Figure 3.5</td>
<td>Conceptual diagram of IWS</td>
<td>49</td>
</tr>
<tr>
<td>Figure 3.6</td>
<td>The video camera used in RBPR system</td>
<td>51</td>
</tr>
<tr>
<td>Figure 3.7</td>
<td>Physical waste</td>
<td>54</td>
</tr>
<tr>
<td>Figure 3.8</td>
<td>Non value-added activities</td>
<td>55</td>
</tr>
<tr>
<td>Figure 3.9</td>
<td>Components of waste in construction</td>
<td>56</td>
</tr>
<tr>
<td>Figure 3.10</td>
<td>Cause-and-effect of non value-added activity and physical waste</td>
<td>57</td>
</tr>
<tr>
<td>Figure 3.11</td>
<td>Visual as-built for the home owner</td>
<td>59</td>
</tr>
<tr>
<td>Figure 3.12</td>
<td>2 X 2 value payoff matrix</td>
<td>61</td>
</tr>
</tbody>
</table>
Figure 3.13  3 X 4 value payoff matrix .................................................. 62
Figure 4.1  Available visual information of Knightdale construction site .... 67
Figure 4.2  Balloon testing ................................................................. 68
Figure 4.3  Visual as-built for lot 19 .................................................... 69
Figure 4.4  Videotaping used in process improvement study ................... 70
Figure 4.5  Components of the V-IWS ............................................... 76
Figure 5.1  V-IWS installations ........................................................... 82
Figure 5.2  Samples of picture from the network cameras ....................... 84
Figure 5.3  Floor plan of the USTL building ....................................... 87
Figure 5.4  Measurement of signal strength and link quality
inside the building ........................................................................ 88
Figure 5.5 (a) Signal strength from RP-1 ............................................ 90
Figure 5.5 (b) Link quality from RP-1 ................................................ 91
Figure 5.6  Field intensity from RP-1 .................................................. 92
Figure 5.7 (a) Signal strength from RP-2 ............................................ 94
Figure 5.7 (b) Link quality from RP-2 ................................................ 95
Figure 5.8  Field intensity from RP-2 .................................................. 96
Figure 5.9  Network camera on the roof of Garner Hall building ............ 97
Figure 6.1  Percent of information transferred in the USTL’s meetings ...... 104
Figure 6.2  Online message board ..................................................... 108
Figure 6.3  The greenhouse material delivery ...................................... 111
Figure 6.4  Timeline of the greenhouse material delivery ...................... 113
Figure 6.5  Collateral waste caused by the truck waiting outside ............. 114
Figure 6.6  Online material planning tool .......................................... 116
Figure 6.7  Value rating based on system’s features ............................. 119
Figure 6.8  Comparison of overall value rating ..................................... 121
Figure 6.9  Cost-benefit comparisons at various % reductions of meetings ... 128
1. INTRODUCTION

1.1 Performance Review of the Construction Industry

The construction industry is one of the largest non-farm sectors in the U.S. economy. According to U.S. Census Bureau, in 1997 the construction industry performs more than $845 billion of work or almost 11% of GDP and employs more than 5.6 million employees. Due to its size, the performance of construction industry is important for the growth of the entire U.S. economy. However, statistics show that the industry has been suffered from low performance for more than three decades. This low performance includes low productivity, high accident rates, late completion, and poor quality. Since 1964, the labor productivity of construction industry has been stagnated compared to that of average all non-farm industries (Teicholz, 2000). In addition, according to Occupational Safety & Health Administration, construction industry had 1,121 fatal injuries in 2002, the highest number of any major industry (OSHA, 2003).

Many project managers believe the single most important factor that contributes to successful project management is communications (CII Publication 7-1, 1986). General contractor and his subcontractors cannot perform construction activities without information. Love (1997) suggested that subcontractors rely heavily on general
contractor for developing open communication and only by including the subcontractors in communications and decision processes that a higher level of trust can be achieved. The concrete subcontractor needs to know if there is any change in dimension or elevation of the concrete slab before he prepares the formwork and rebar. The architect may think that he can make a change and not affect the subcontractor because the slab has not been cast. However, making such a change causes the subcontractor to rework formwork and rebar. Typically, a construction project needs one entity to act as a leader to conduct and coordinate other entities to work smoothly together. This entity can be the owner, the architect, or the general contractor depends on the phase of the construction project. During the design phase the leader may be the architect while during construction phase the general contractor is usually the one who coordinate the team. Regardless of who is the leader, having the right information to the right person at the right time is proven to be vital to the project’s success.

Even though construction managers have put a lot of effort into improving overall project performance, the results are far from satisfied. Successful construction projects require collaboration and sharing of information from every party involved. However, the traditional culture along with vertical organization that can be seen as a tall, thick, and windowless or so-called “silo phenomenon” have prevented the managers from recognizing needs or constrains of other project participants. Rummler and Brache (1990) defined silo culture as individual departments or “silos” who perceived other departments as enemies rather than partners. For teamwork development, the silo
phenomenon also prevents “cross-functional issues” being solved at lower level and causes problems to escalate to the top of the silo (Castka, 2002). In construction industry, silo culture does not exist only within organization but also among different organization such as general contractors, designers and subcontractors. A recent research project revealed that subcontractors often complain about the quality of information received from general contractors such as missing, late and inaccurate design drawings (Dainty, Briscoe and Millett, 2001). It is seen that the silo culture has created a barrier for critical information to flow smoothly among project participants.

1.2 Low Performance Caused by Asynchronous Information

According to the book “Out of the Crisis” by Dr. Deming, 94% of troubles in engineering system and possibilities for improvement belong to management responsibility (Deming, 2000). The manager usually blames weather, changes, or environment for low productivity, but in reality most of the failure is caused by poor instruction or supervision (Stukhart, 1995). A research done by interviewing a variety of staff from general contractor, subcontractors and suppliers showed that quality of information was one of main barriers to more efficient working relationships in construction supply chain. (Dainty, Briscoe and Millett, 2001).
The lack of effective communication is also a major obstacle to project success. The Construction Industry Institute (CII) conducted a survey research to identify the critical communications variables that effected project’s success. The survey included 35 owner and contractor firms and 3 government agencies. A total of 582 returned questionnaires revealed that 41% of the variation in perceptions of project success could be attributed to variation in communication effectiveness (Thomas, Tucker, and Kelly, 1998). This indicates a direct relationship between communication effectiveness and project success. The survey strongly suggested that improved project communications would lead to higher project performances.

Table 1.1    Foremen’s main source of delay (Source: Elliot 2000)

<table>
<thead>
<tr>
<th>Source of Delay Cited</th>
<th>Percent of Foremen Citing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unanswered Questions</td>
<td>42.6</td>
</tr>
<tr>
<td>Other Trades</td>
<td>37.7</td>
</tr>
<tr>
<td>Incomplete or Conflicting Plans/Specifications</td>
<td>31.0</td>
</tr>
<tr>
<td>Scheduling, Coordination, and Communication</td>
<td>28.7</td>
</tr>
<tr>
<td>Changes to the Work</td>
<td>27.8</td>
</tr>
<tr>
<td>Material Delays</td>
<td>25.4</td>
</tr>
<tr>
<td>Weather</td>
<td>14.4</td>
</tr>
<tr>
<td>Manpower</td>
<td>10.5</td>
</tr>
</tbody>
</table>

In a separated research survey given to 119 foremen in 11 construction projects to identify problems existed in the scheduling communication process showed that the source of delay most cited by the foremen was unanswered questions (Elliot, 2000). The
result of the survey is shown in Table 1.1. Incomplete or conflicting plans/specifications and scheduling, coordination and communication were also cited as source of delay by majority of the foremen. In addition, the research also showed that foremen were partially excluded from the flow of information within the communication process. The research suggested that the process could be improved by increasing foremen’s involvement and enabling foremen to access the information they needed in order to coordinate the work.

In late 1996, a large mechanical contractor worked on a pilot project which employed approximately 50 plumbers, pipe-fitters, and sheet metal workers. The study measured the PPC (Percent Plan Complete: number of completed assignments divided by the total number of assignments) of weekly work plans during the week of 10/7/96 through the week of 1/20/97. Of the 249 incomplete assignments, the top 3 reasons why they were not completed on time were as follow: 1) 71 cases were because of late or defective materials, 2) 42 cases were because of the prerequisite work was not completed, and 3) 37 cases were because of changes in priorities (Ballard, 1997). It appears that all these 3 reasons relate to lack of coordination between suppliers and other trade involved in the processes.

Having synchronous information sharing among project participants is vital for project success. Lack of accurate information to the right person at the right time is the
major source of delay, cause a great deal of waste and severely affect project performances.

1.3 Problem Statement and Need

The U.S. Economic Census 1997 showed that there were more than 6 hundred thousand establishments in construction business performed work such as general contractor, subcontractor, designer, etc. not included material suppliers (U.S. Census Bureau, 2002). The majority of these establishments were small and medium business. For instance, according to “Structure of the Residential Construction Industry” by Gopal Ahluwalia and Jo Chapman, the 1997 Census of Construction showed that 73,500 residential home builders built less than 25 homes but accounted for 39% of all the homes built. These builders had an average of only 4 employees on the payroll. Builders who built less than 100 units accounted for another 21% and had an average of 8 employees on the payroll (NAHB Research Center, 2001).

It is not uncommon for a construction project to have more than 10 parties from different companies involved in the project at the same time. These parties consist of an owner, designers, a general contractor (GC), subcontractors, and suppliers. For a particular project, these parties will send their delegates to perform their assigned function for the project. These delegates will form a temporary organization with each
other. This organization can be called “cross-functional supply chain” (CFSC) team. London and Kenley (2001) pointed out that due to the temporary nature of this organization, any managerial concepts applied to a project in construction environment was problematic.

The call for modern management concepts in construction is not new. In the late 1970s, a business roundtable task force found that there was deficiencies in almost all aspects of the construction, ranging from planning and design through the site operation. Its reports were widely distributed. One of the reports addressed the issue of modern management method awareness as quote: (Oglesby, Parker and Howell, 1989).

“The construction industry has been criticized, to a large extent justifiably, for its slow acceptance and use of modern management methods to plan and execute projects. Many people both inside and outside the industry view this as a primary cause of serious delays in schedules and large cost overruns that have plagued the industry in recent years. Yet there is no lack of modern cost-effective management systems that can provide project managers with all the controls they need.”

Due to fragmentation of the industry and temporary relationship of CFSC team, it is extremely difficult to apply modern management concepts without using information technologies to increase communication efficiency among CFSC team. It is clear that a research in the area of improving communication using state-of-the-art technologies is need to be done in order to improve the industry’s performance and maintain its ability to compete in the global market.
1.4 Research Objectives

The goal of this research is to investigate the effectiveness of visual-based information logistics model on construction process’ performances. The more specific research objectives include:

1) Study and evaluate key communication channels used today in construction as well as the state-of-the-art technologies that could underpin a synchronous information logistics model.

2) Analyze the information flow between the main team members of a mid-size building construction project.

3) Develop and test a prototype web-based communication system to support real-time and interactive information sharing among all project participants, both technical and non-technical.

4) Assess the effectiveness of the prototype web-based information system in reducing production waste and adding value for different project participants including the users of the building.
1.5 Organization of the Thesis

This thesis is organized into 7 chapters. Chapter 1 gives an overview of performance problems in construction industry and emphasizes the importance of communication among project participants. Research problems and the objectives of the research are presented. Chapter 2 reviews literature concerning input and output of construction process, nature of information flow among project participants, managerial concepts and state-of-the-art communication technologies necessary for conducting the research. The concept of Integrated Wireless Site (IWS) aimed to reduce waste in construction based on lean thinking is proposed in Chapter 3. Models to describe production waste, the issue of collaboration and value sharing are discussed in this chapter. Chapter 4 presents the development of the IWS’s prototype system named Visual-based IWS (V-IWS) focusing on real-time visual information made available for authorized project participants through the Internet. Chapter 5 describes the installation of the V-IWS at Undergraduate Science Teaching Lab (USTL) site on NC State Campus followed by data collection and analysis in Chapter 6. Finally, Chapter 7 concludes the thesis with a summary of the results and guideline for future study. The appendices hold detailed information of some of the issues discussed in the thesis.
2. LITERATURE REVIEW

This chapter discusses the fundamental concept of construction process as well as the flow of information. Information is recognized as one of the process input. The lean thinking and information logistics are investigated in order to provide fundamental concepts for waste reduction. State-of-the-art technologies in communication and networking are described as the fundamental means to enable information logistics model in jobsite environment.

2.1 Construction Process Review

The construction site operation is very complex and influenced by both controllable and uncontrollable condition (Salim, 1993). Koskela (2000) studied theory of production and applied to construction process by reviewing the history of production thinking. He found that there were three different conceptualizations of production: 1) Production was viewed as a transformation of inputs to outputs or so-called “transformation concept.” 2) Production could be viewed as a flow of products from one worker to another (raw materials gradually moved to become finished products or “flow concept.” 3) Production as a means for the fulfillment of the customer needs or “value
generation concept.” He also noted that all three concepts were necessary and should be utilized simultaneously. Based on his research, all three concepts of production can also be applied into construction (Koskela, 2000).

2.1.1 Resources as Process Inputs

According to Koskela (2000), construction process was seen as a transformation of a set of resources or input into a modified form or output. The transformation process, then, could be decomposed into sub-processes, which also be considered a transformation processes.

![Figure 2.1 Transformation concept of production (Based on Koskela, 2000)](image)

The concept of transformation is shown in figure 2.1. A process of building a residential home, for example, composes of foundation, framing, roofing, and etc. The foundation sub-process is decomposed into excavation, reinforcing, forming, concrete
casting, and so on. Each transformation process and sub-process in construction is affected by outside conditions; some can be controlled, but some is considered uncontrollable.

Figure 2.2 Input/output process model (Based on Salim, 1993)

Salim (1993) has proposed the Input/Output process model as shown in figure 2.2. The model is composed of five parts: inputs, process, outputs, uncontrollable conditions, and controllable factors. Many different types of resources are required as “ingredients” in order to start and sustain a construction process. The performance of processes and
quality of the outputs depend largely on the state of the inputs. Labors, materials, equipments, drawings, specifications, instructions, and utilities are examples of resources that need to be at the “point of consumption” at the right time and with the right quality.

2.1.2 Recognition of Information as a Resource

According to input/output process model shown in figure 2.2, information is recognized as one of process inputs. Information, as defined by Merriam-Webster Dictionary, is knowledge obtained from investigation, study, or instruction. It is different from data in the way that data have to be processed into a meaningful form before it can be turned into information (Senn, 1990). In construction, specification, instruction, as well as schedule are all considered vital information. Furthermore, each resource including material, labor or equipment all has pieces of information associated with them. Materials, for instance, have their quality, quantity, handling instruction, delivery date, and loading area assigned to them.

Inaccurate and delayed information can cause serious performance problem to the process. Because of the importance of information, it needs to be managed and recognized as a critical resource. Figure 2.3 shows a sample of materials and their associated information that flows along. The supplier would have never known when and where the material needs to be delivered if nobody tells him. Those pieces of
information, somehow, need to be flowed to him at an appropriate time so he can manage to have the material flown to the process at the right place and the right time.

2.1.3 Activity Planning versus Process Planning

The objectives of planning are to complete a prescribed amount of work within the required time limit, within the budgeted cost, and to the specified standard of quality (Zhang, 2001). Construction planning can be done in both activity level and process level. According to Zhang, the term “activity” in construction is any portion of a project,
which consumes time or resources and has a definable beginning and ending. The activity, then, can be broken down into process, work task, and motion/move. For instance, basement activity can be broken down to reinforced steel process, formwork process, placing concrete process, and etc. The reinforced steel process composed of several tasks such as cut, bend, and place. Most of construction project has been planned and scheduled at activity level, i.e. foundation, first floor beam, column, second floor beam, etc. Each activity, then, will be assigned tentative duration, relationship, resources, etc. Managers use activity planning to prepare a network model, scheduling, and resource allocation. This approach, however, does not focus on process of how to complete the activity but concentrate on the completion of the activity. In other words, activity planning concentrates largely on targets. In target-based planning, managers set the targets that are time, budget, quality, etc. and try to ensure that those targets are met. The management may not make any adjustment to improve performance as long as the work progresses according to the plan and within allowable mistakes. In addition, target-based planning cannot monitor and control waste or spot problems during the process as long as the activity meet the targets i.e. finished on time, within the budget, and pass the inspection. The quality defects usually are spotted after the activity finished in which discards or reworks are unavoidable.

In contrast to activity planning, “process planning” focus on the process level. Process planning is considered proactive by concentrating on flows of the processes. More attention is paid to input and the process itself rather than output in order to prevent
the problem before it occurs. Compared to activity planning, process planning is not used widely in the construction industry (Zhang, 2001). Most of the time, planning of a process has been done by superintendent at the job site on week-to-week or, sometimes, day-to-day basis. However, in the dynamic environment of construction site, researches have shown that the development of process-based planning has the significant impact on productivity and performance of the project. Activity planning cannot be accurately detailed so far into the future because of the lack of information about actual durations and deliveries (Ballard, 1997). On the other hand, process planning ensures that the crew working on the job will be able to work with all the resources available.

2.2 Communication in Construction Project

A successful project requires the collaboration and sharing of information from the owner (customer) and numerous multidisciplinary professional including designers, general contractors, subcontractors, and suppliers. Communication among these participants can be both formal and informal. Informal communications are necessary in order to complement the deficiencies and clarify the uncertain meaning of formal communication (Attia, 2002). The traditional channels of communication are face-to-face meeting, letter, fax, phone/radio, and telephone. Some new channels such as electronic mail and digital documentation are also become widely used. These channels have their disadvantages. Face-to-face meeting, for instance, while provides an effective
ways to communicate with each other requires every body to be available at the same time and it is both timely and costly. Besides, the information communicated by face-to-face meeting is delayed, sometimes weeks or months.

Figure 2.4 Information flow diagram (Based on Oglesby, Parker and Howell, 1989)
Traditionally, information in a construction project can be flown in two directions: 1) between superior and subordinate, and 2) among CFSC team. The information that flow between superior and subordinate is called “vertical flow.” Figure 2.4 shows an example of information flow diagrammed in construction project based on Oglesby, Parker and Howell (1989). Downward flows involve such item as plans, instructions, orders, and etc. both formal (usually written) and informal (usually verbal). Upward flows show feedback of problems, progress, data collection, and etc. It is important to note that communications of any kind involved a very complex process can be strongly influenced and possibly biased by those who generate and transmit information. From the diagram, information flown from contractor to crew at work face is considered to be in vertical direction while the flow between owner’s representative and contractor can be seen as either vertical or horizontal direction.

Figure 2.5 Communication flow in a construction alliance (Cheng et. al., 2001)
Although the information flow diagram based on Oglesby shows how information flows from the owner to the contractor and down to the crew at the work face. It does not show how information flows among the CFSC team. Cheng et al. (2001) studied the communication network within multiple parties involved in construction project. The communication flow based on Cheng is shown in figure 2.5. This model suggests that each party in the CFSC team has the right to communicate with all other parties. The relationship between each member is typically contractual and the flow of information among member is considered horizontal.

2.3 Information Logistics

The term “information logistics” is relatively new. It is considered part of overall logistics concept. Council of Logistics Management (CLM), a not-for-profit professional association for people interested in logistics management, defines logistics as a part of the supply chain process that plans, implements, and controls the efficient, effective flow and storage of goods, services, and related information from the point of origin to the point of consumption in order to meet customers’ requirements (http://www.clm1.org, 2001). From this definition, the scope of logistics covers two major parts: “physical logistics” and non-physical or “information logistics”. The physical logistics network in manufacturing industry consists of manufacturing plants, suppliers, distribution center, warehouses, retail stores, and customers including raw material, work-in-progress (WIP),
and finished products that flow between the facilities as shown in figure 2.6 (Bramel and Simchi-Levi, 1997). Due to the fact that physical logistics deals with moving “physical” things from point-of-origin to point-of-consumption, therefore the attributes of things (e.g. weight, volume, shape, etc.) and distance between nodes of transportation are the major concerns in design and manage the logistics system. The great economic constraints involved in physical logistics are time and cost. The revolution in physical logistics began with the emerging of railroad, motor vehicles, and aviation. However, increasing in physical logistics efficiency needs to accompany with efficiency flow of related information.

Figure 2.6 Physical logistics network (Based on Bramel and Simchi-Levi, 1997)
Information logistics deals with the non-physical components of logistics defined by CLM. It has become more and more important in military operation. According to the article “Survey Defence Technology” published by The Economist in 1995, during the Gulf war the allies suffered from various types of information shortage. Three-quarters of the American vehicles destroyed or damaged were hit by their own side. Mellyn and Groeve (2000) defined the information logistics revolution as “the ability to exchange and process ever-increasing volumes of information between economic actors at ever-decreasing cost to achieve just-in-time procurement manufacturing and distribution.” They also suggested that optimizing physical logistics was impossible beyond a certain point before better information logistics were applied to the problem. In fact, business was increasingly building linkages between their own internal information system, typically ERP systems, and those of their suppliers and customers. In construction, Soibelman and Caldas (2000) defined information logistics for construction design team collaboration as “the maintenance, tracking, monitor and enactment of information flows within design organizational process. The aim was to support inter-organizational information system in order to assure that the accurate and relevant information would be on the right place at the appropriate time and with the required quality.”

Recently, the concept of logistics has been expanding to cover the flow of products over their entire life cycle. According to Schonsleben (2000), logistics in and
among companies is the organization, planning, and realization of the total flow of goods, data, and control along the entire life cycle of products. The life cycle begins with environment and consists of three phrases: design and manufacturing, use, and disposal, then it returned to environment as shown in figure 2.7.

![Logistics life cycle diagram](Based on Schonsleben, 2000)

The study in logistics, which was once understood as storing and transportation of goods, is changed to focus on an integral perspective on company coordinated business process. Storing and transportation are still necessary but now these processes are seen as disturbing factors or “waste” that should be reduced as much as possible (Schonsleben, 2000). In addition, logistics of goods or physical resources alone is no longer sufficient. Information logistics is an imperative part of integral logistics for the company in order to remain competitive.
2.4 Waste Concepts Based-on Lean Thinking

There are several terms that closely relate to the term “lean thinking.” Just-in-Time (JIT), Toyota Production System (TPS), Kanban System, and Pull System are all related and, sometime, confuse with lean thinking. Even though the term “lean” was coined by the research team working on international auto production, the idea was developed by Toyota’s engineer, Taiichi Ohno (Howell, 1999). Mr. Ohno began to develop a system so-called “Toyota Production System” after Japan lost in the World War II. The most important objective of the system was to increase production efficiency by consistently and thoroughly eliminating waste (Ohno, 1988). The TPS has become a huge success and the system has been adopted by other companies worldwide. However the system is based on trial-and-error process and the company’s culture; therefore make it difficult for outside people to understand. This was emphasized by the foreword of Monden’s Toyota Production System book by Mr. Ohno himself (Monden, 1998).

“The technique we call the Toyota production system was born through our various efforts to catch up with the automotive industries of western advanced nations after the end of World War II, without the benefit of funds or splendid facilities. Above all, one of our most important purposes was increased productivity and reduced costs. To achieve this purpose, we put our emphasis on the notion of eliminating all kinds of unnecessary functions in the factories. Our approach has been to investigate one by one the causes of various “unnecessaries” in manufacturing operations and to devise method for their solution, often by trial and error. The technique of Kanban as a means of Just-In-Time production, the idea and method of production smoothing, and Autonomation (Jidoka), etc., have all been created from such trial-and-error processes in the manufacturing sites. Thus, since the Toyota production system has been created from actual practices in the factories
of Toyota, it has a strong feature of emphasizing practical effects, and actual practice and implementation over theoretical analysis. As a result, it was our observation that even in Japan it was difficult for the people of outside companies to understand our system; still less was it possible for the foreign people to understand it. …”

…but Taiicho Ohno Former Vice President, Toyota Motor Corporation

One of the key components of TPS is Just-in-Time (JIT). JIT was first implemented at TOYOTA production plants in the early 1970s as a method of reducing inventory levels. The philosophy of JIT is to meet customer demand with minimum delays (Cheng and Podolsky, 1996). The most important concept in JIT is “people” or employee involvement. JIT considers workforce as an intellectual as well as physical resources. This is emphasized by Cheng and Podolsky (1996) statement: “People are the only resource within an organization that can create differentiation between one company and its competitors.” The kanban or pull system is the method that the production is base on actual demand (Low and Mok, 1999). The word “kanban” is a Japanese word means “signal.” It is usually a card or tag accompanying work-in-process. The advantage of kanban or pull system is to reduce waste caused by inventory and storage space. Purchasing and delivery orders are base on actual requirements on site rather than schedules prepared much earlier in the project. Despite having been proven to be an effective concept for eliminating waste and add value to the customer, JIT must be carefully implemented especially in the area of unexpected change. There could be sudden shortages of supply from sudden uncontrollable external factors such as weather and earthquake (Low and Mok, 1999). For instance, the 1996 Kobe earthquake and the incident on September 11th had disrupted many JIT production supply.
Based on the concept of Toyota Production System and JIT philosophy, the term “lean thinking” was established. The word “lean” was used because it provided a way to do more with less that mean used less resources to create more customer’s value. There are two words that critical in the concept of lean: “waste” and “value.” Ohno defied waste or “muda” in Japanese word as all elements of production that only increase cost without adding value. Production waste can be divided into 7 categories as follow (Ohno, 1988): 1) Over production, 2) Waiting, 3) Transportation, 4) Too much machining (over processing), 5) Inventory, 6) Moving and 7) Making defective parts and products. Ohno categorized his muda based on physical production environment. Womack and Jones (1996) suggested that there may be more muda and they have added the design of goods and services which do not meet users’ needs as the eighth muda. Value, on the other hand, is hard to define. Womack and Jones stated that value could only be defined by the ultimate customer and it was meaningful when expressed in term of a specific product (a good or a service) which met the customer’s needs at a specific price at a specific time

Recently, “lean thinking” has become the topic of interest in construction industry. Lean construction focuses on customer’s value and elimination of non value-added activities. According to Koskela (2000), construction process can be viewed as the value generation process. In this aspect, the focus is on customer’s satisfactions and more attention is paid to all suppliers’ activities such as customer service and timeliness
rather than just physical output. Anything that does not add value and satisfy customer is considered waste. Excess inventory, unnecessary transportation, too many meetings, or even bidding process can be considered wasteful and should be eliminated. Meetings, for instance, involve costs beyond the costs of travel and loss productivity. Unnecessary meetings consume most of the managers’ time and cause a lot of stress. According to the MCI conferencing paper (1998) “Meetings in America,” 37 percent of employee time is spent in meetings. Busy professionals attend over 60 meetings each month. The study also reveals that the majority of attendees are concerned about other work responsibilities that pile up at their office and feel stressful to travel, especially when they have to stay away from family.

Some non value-added activities, however, are arguable and some may not able to be eliminated immediately. The bidding process, for example, by itself does not add value to the customer but it is considered a way to find a low price which is adding value to the customer. However, the process itself is costly and when considers the successful rate of approximately 10%. This cost will be passed on to the customer that is, in turn, destroy customer’s value (Josephson and Saukkoriipi, 2003). Doyle Wilson, a home builder in Austin, Texas. The company decided to eliminate traditional “builder bonus” which was for its construction superintendents who completed the job on time. The company considered this bonus as a motivation for the superintendent to make a side deal with customers on a “to-be-done-later” list (Womack and Jones, 1996). For others,
however, the builder bonus is considered an incentive that encourages superintendents to finish the project on time.

2.5 Information Technologies

As mentioned earlier in section 1.3, the construction industry is fragmented and it is difficult to apply managerial concepts such as supply chain, logistics, and lean thinking without the use of technology. This section reviews information technologies that can be used to improve information flow in construction projects.

2.5.1 MRP II, ERP, and CERP

Both Manufacturing Resource Planning (MRP II) and Enterprise Resource Planning (ERP) are the extension of MRP (Material Requirement Plan) (Wight, 1983). According to APICS Dictionary 1992, MRP II can be defined as “a method for the effective planning of all resources of a manufacturing company.” MRP II is made up of a variety of functions such as business planning, production planning, master scheduling, material requirement planning, and capacity requirement planning, each linked together. It addresses operation planning, financial planning, and has a simulation capability to answer “what-if” questions (Ip and Yam, 1998). According to Wight (1983), as of mid
1981, there are approximately 8,000 manufacturing companies in the United State that are using some form of MRP.

ERP (Enterprise Resource Planning) shares the same fundamentals with MRP II but is broader in scope to include financial, supply chain, and supporting business units across company boundaries (Wallace and Kremzar, 2001). While MRP II focuses on manufacturing production, ERP enhances management of all business operation across the enterprise. In a simple term, ERP is a computer program that provides a general working platform for all departments of an enterprise with their management functions being integrated into the program (Shi and Halpin, 2003). The world’s largest ERP providers include SAP, Oracle, and People Soft, while the most popular system installed worldwide is SAP R/3 (Jacobs and Whybark, 2000). Many researchers in the area of ERP believe that ERP is the driving technology of BPR or business process re-engineering (Al-Mashari, 2003). Traditional ERP is intended to be used within organizations. According to Mellyn and Groeve (2000), however, many businesses today are trying to link their ERP system and share information with their customer and suppliers along the supply chain as well.

In construction environment, information is generated by CFSC team member who is delegated from different company. In order to have information flow effectively, each team member must cross over organizational barriers between companies. An ERP system maintains one single database. When a piece of information has been entered, it
is stored in the central database and is available to all eligible users in the system (Shi and Halpin, 2003). Sharing the same database eliminates the need of regenerating or reentering the same information which helps maintain data consistency, and reduces human errors. ERP supports one time entry of information where it is created, then the information is save into the database and available to all participants. According to the study by ML Payton Consultants, the ERP market could reach $52 billion by 2002. The implementation of the ERP system normally takes 1-2 years in average (Ahmed and et al., 2003). Despite its huge market, ERP systems still have several disadvantages. The systems are expensive and difficult to implement. According to a survey of 15 implementations, the systems were costs from $2 million to $130 million (Ross, 1999). Nevertheless, several implementation failures are reported. Statistics show that the majority of ERP implementations could not be completed in scheduled duration and within budget (Shi and Halpin, 2003).

Figure 2.8 Conceptual CERP architecture (Shi and Halpin, 2002)
Traditional ERP systems such as SAP are not primarily developed for construction (Shi and Halpin, 2003). Shi and Halpin (2003) suggest the Conceptual Construction Enterprise Resource Planning (CERP) based on three-tiered client/server architecture as shown in figure 2.8. The primary function of the first tier is to interface with the various users across a construction enterprise such as purchasing and operations. The second tier is the management server which provides system administration and acts as a bridge between the users and the central database and applications. The third tier is comprised of the applications and the central database which contains cost data, project data, equipment data, and etc. The applications are organized into corporate-level, project-level, and back-office applications.

According to Lee et al. (2002), a simulation model showed that implementing ERP in the construction material management system could shorten procurement cycle by approximately 80 percent. In today competitive market, it is clear that implementing some form of ERP system is vital. However, a standard, best methodology for implementation, especially for construction, does not exist. A questionnaire survey of 12 contractors showed that many contractors feared that ERP system would not work well in their organization due to the small size of the organization, limited resources and not adequate technical skills. Majority of the respondents (42%) showed low level of satisfaction on the performance of ERP system and only 8% showed high level of satisfaction (Ahmed et al., 2003). Researches have shown that the future trend of ERP needs to be scalable and easy to implement. According to Gupta (2000), the next
generation of ERP will have to incorporate the Internet in its applications such as web-based procurement system.

2.5.2 Network, the Internet and TCP/IP Protocols

A computer network consists of two or more computer /network devices that connect to each other by communication medium. The medium can be wire or wireless. The examples of “wire” medium are Ethernet cable, coaxial cable, or fiber optic cable. Different types of cable support different data transfer speed. Wireless medium, on the other hand, uses electromagnetic wave such as radio wave, microwave, or infrared as a medium to transfer data between devices in a network. The main objective of having a network is to share resources. The resources can be hardware and/or software including printers, scanners, and software applications. However, the most important shared resource that make computer network so promising is information. The information that can be shared by the network is anything that can be transformed into digital format such as text, graphic, photo, video, voice, data file, and etc. One network can also be connected to another network through a device called “router.” A network that connects computers within small area such as in a building is called “Local Area Network or LAN” while the one that connects larger area such as a couple buildings or a city is called “Wide Area Network or WAN.”
Due to the critical role of computer network as a means to transfer information and communication, during 1960s, the Department of Defense along with researcher at universities and large technology companies like Xerox formed a working group called Advanced Research Projects Agency (ARPA). The objective of this team was to develop a way of passing data among widely separated nodes in case the country was attacked by nuclear weapons. The outcome of this team was ARPANET (Patil et al., 2003). At the beginning, ARPANET was limited to government, universities, and some research organizations. Until 1989, ARPANET was opened to public and became the Internet (Duntemann, 2003).

The Internet can be considered as “a network of networks.” Due to the fact that there are different kinds of operating system used worldwide, the Internet uses an open standard protocol system called Transmission Control Protocol / Internet Protocol or TCP/IP. TCP/IP uses package switching method to send information over the Internet. All data will be broken up into small chunks. Then each chunk will be added with information containing the address of where it is coming from and where it is going. Today, the address system used is Internet Protocol version 4 or IPv4. An IP address consists of four groups of number separated by dot such as 192.168.0.101. Since the IPv4 is 32 bits, therefore the number in each group must be between 0 and 255. The current IP standard separates an IP address into two parts: one is the address of the network and the other is the address of a particular node or host. How the number is
separated depends on what class it belongs to. Figure 2.11 shows how an IP address is separated (Duntemann, 2003).

IPv4 categorizes IP addresses into 3 classes. IP addresses will be assigned according to the size of possible hosts. In addition, some certain ranges of IP are reserved as “local IP addresses” for example 192.168.0.0 to 192.168.255.255 in Class C. The local IP addresses are non-routable that means they are known only within a LAN.

There are three regional Internet registries responsible for the assignment of IP addresses: ARIN (American Registry for Internet Numbers) responsible for North America, South America, the Caribbean, and sub-Saharan Africa; APNIC (Asia Pacific Network Information Centre) responsible for Asia Pacific region; and RIPE (Reseaux IP Europeens) responsible for Europe and beyond (Patil et al., 2003).
IPv4 can supply more than 4 billion IP addresses. In the past, most of the IP addresses were allocated to American universities and organizations. For example, Stanford University was given more than 17 million addresses, while India, which had more than 1 billion in population, had 2 million addresses (Erlanger, 2003). With today advancement in technology, not only computer servers or hosts that require addresses but also many kinds of device such as PDAs, cell phones, automobiles, and home appliances need IP addresses in order to connect to the Internet. Experts estimate that sometime within the next decade, IPv4 will run out of the addresses. Today researchers are working on the next generation of Internet Protocol called IPv6. Since IPv6 is 128 bits, it will increase the supply of IP addresses from 4 billion to over 35 trillion (Erlanger, 2003).

The Internet and networking have tremendous effects on the U.S. economic. Former Federal Reserve Vice-Chair Alice M. Rivlin said “… gains from businesses using the Net to sharpen forecasting, keep inventories lean, and communicate instantaneously with suppliers could reach $450 billion a year by 2005. Spread across the economy in lower prices that would add $4,500 annually to the average U.S. household’s income – more than three times the amount of President Bush’s 2001 tax cut.” However, according to New York Federal Reserve Bank economist Kevin J. Stiroh, about a third of the economy, including agriculture, construction, and health care, has barely been touched by the Net-driven productivity boom (Mullaney et al. (2003)).
2.5.3 Wi-Fi

Wi-Fi (Wireless Fidelity) is a radio-based networks technology that connects computers or wireless devices compatible with Institute of Electrical and Electronic Engineers (IEEE) 802.11x standards. There are four 802.11x standards have been approved by IEEE as shown in Table 2.1 (http://www.wlana.org). Other standards such as 802.11e, 802.11f, 802.11h and 802.11i are still in development. The current status of the standards can be found at the website of The Institute of Electrical and Electronics Engineers, Inc., (http://www.ieee.org) and The Wireless LAN Association (http://www.wlana.org).

Table 2.1 Approved 802.11x standards (http://www.wlana.org)

<table>
<thead>
<tr>
<th>Standard</th>
<th>Description</th>
<th>Approved</th>
</tr>
</thead>
<tbody>
<tr>
<td>IEEE 802.11</td>
<td>Standard for WLAN operations at data rate up to 2 Mbps in the 2.4-GHz ISM (Industrial, Scientific and Medical) band.</td>
<td>July 1997</td>
</tr>
<tr>
<td>IEEE 802.11a</td>
<td>Standard for WLAN operations at data rate up to 54 Mbps in the 5-GHz Unlicensed National Information Infrastructure (UNII) band.</td>
<td>September 1999.</td>
</tr>
<tr>
<td>IEEE 802.11b</td>
<td>Standard for WLAN operations at data rate up to 11 Mbps in the 2.4-GHz ISM band.</td>
<td>September 1999.</td>
</tr>
<tr>
<td>IEEE 802.11g</td>
<td>High-rate extension to 802.11b allowing for data rates up to 54 Mbps in the 2.4-GHz ISM band.</td>
<td>June 2003.</td>
</tr>
</tbody>
</table>

In more than 90 General Motors plants, Wi-Fi devices are mounted on forklifts to track engine parts and car seats to speed production (Mullaney et al. (2003). Wi-Fi network also helps United Parcel Service improves productivity by 35% (Green et al.,
2003). Wireless LAN Association (WLANA) conducted a survey on wireless LAN return on investment. 34 organizations in 5 industries were interviewed regarding costs and benefits of wireless LAN (WLAN) implementation. The results of the survey are summarized in Table 2.2. The payback period is the period of time required for the cumulative cash flows due to increased productivity, organizational efficiency and extra revenue/profit gain to equal the initial investment. The survey also shows that organizations implementing an average of 300 client cards gained annual savings of up to $4.9 million (Armenta, 2001).

Table 2.2 WLAN costs/benefits study (Armenta, 2001)

<table>
<thead>
<tr>
<th></th>
<th>Retail</th>
<th>Manufacturing</th>
<th>Healthcare</th>
<th>Office Automation</th>
<th>Education</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benefits per company (millions $)</td>
<td>5.6</td>
<td>2.2</td>
<td>.94</td>
<td>2.5</td>
<td>.5</td>
</tr>
<tr>
<td>Costs per company (millions $)</td>
<td>4.2</td>
<td>1.3</td>
<td>.90</td>
<td>1.3</td>
<td>.3</td>
</tr>
<tr>
<td>Payback (# of months)</td>
<td>9.7</td>
<td>7.2</td>
<td>11.4</td>
<td>6.3</td>
<td>7.1</td>
</tr>
</tbody>
</table>

Over the past few years, the wireless industry has become phenomenon. Wi-Fi networks, known as “hot spots”, have become widespread. The new joint venture made up of Intel, IBM, and AT&T is building a nationwide of 20,000 public hot spots over the next three years, not include some 5,000 free hot spots that have already emerged. These hot spots will allow users to have access to broadband Internet almost anywhere from street corner, coffee shop, even on the airplane. By early 2004, more than 100 Boeing
jets are scheduled to be equipped with Wi-Fi networks. Nearly 4,000 planes are planned to have the service in the next 10 years (Green et al., 2003).

2.6 IT Implementation in Construction

In 1998 Construction Industry Institute (CII), a consortium of owners and contractors, conducted a survey on IT implementation in construction organizations. 69 surveys from 34 CII member companies were analyzed. The percent of survey respondents were as follow: owners 51%, contractors 45%, and suppliers 4%. The respondents were categorized into 3 groups: corporate executives (41%), project managers (45%) and information technologists (14%). One of the survey results showed that data management and web were among top priorities in technology investment. The detail result is shown in figure 2.10 (CII’s survey report, 1998). From the figure, IT investment priority varies depending on role of the respondents. While majority of corporate executives gave first priority to data management and web, project managers had no clear first priority but somewhat split priority between data management, engineering applications, and web. The same survey also showed that there was an overall positive attitude and willingness among companies to implement IT technologies, even though IT spending would stay constant or increase slightly in the next 5 years.
In addition to increasing organizations’ performance, global competition also causes pressure on construction industry to help owners reduce the total cost of ownership (TCO) of facilities. In today’s environment, it is clear that people and technologies are equally important to help the industry achieve its goal. O’Conner and Rasdorf (1998) proposed five steps for both owners and the industry to encourage the use of technologies to reduce TCO and add value to engineering services as follow: 1) Owner should insist on deliverables that include facility data in a form they can use as part of an “as-built.” 2) Construction should start to provide good as-built data to the customer as inexpensive as possible. 3) Designers should pay close attention to the new generation of object-orient CAD systems that have open software architecture and insist
on compatibility. 4) Software and hardware vendors should promote interoperability of their product through standards and protocols. 5) All parties should equip their offices with the highest bandwidth internet access affordable and start transition to web-based project pages with document and data available to authorized personal over the web.

2.7 Summary of Problems and Issues

There are evidences that the construction industry’s performance has fallen behind other industry (described in section 1.1). Low productivity, high accident rate, delays, and poor quality are major problems in the industry. Many researches and studies point out that inefficiency in communication and information logistics are major causes of the problems (as discussed in section 1.2). Despite its size, the industry is so fragmented. In addition, the relationship of the participants in a construction project is usually temporary. These characteristics make implementation of any managerial concepts and/or complex system into a construction project extremely difficult (details in section 1.3).

This research has four objectives. First, study and evaluate key communication channel used today in construction project and technologies that can be used to underpin a synchronous information logistics model. Second, analyze the information flow between main team members of a mid-size building construction project. Third, develop
and test a prototype web-based communication system to support real-time and interactive information sharing among all project participants, both technical and non-technical personnel. Finally, to assess the effectiveness of the prototype system in reducing production waste and adding value to all participants including the users of the building. In order to achieve the objectives, the literature review has been done. First, the construction process model, the important of information as a process input, and the nature of communication among project participants have been studied (details in section 2.1 and 2.2). Second, two modern managerial concepts in construction namely information logistics and production waste based on lean thinking are presented as foundations of the new approach in construction information logistics that can be used to reduce production waste and add more value to the participants (details in section 2.3 and 2.4). Finally, state-of-the-art information technologies as well as lessons learned from implementing complex system such as ERP and CERP in construction companies are reviewed and used as tools in order to develop and test the prototype system (details in section 2.5 and 2.6).
3. INTEGRATED WIRELESS SITE (IWS)

As mention in chapter 1, the inefficiency of traditional communication approach which relies heavily on telephone, letter, and on-site meeting is proven to be a major source of delay and waste in construction. In chapter 2, various concepts of construction process, logistics, and information technologies have been investigated to find a better way to improve efficiency of communication system. Understanding of these concepts serves as solid fundamentals to develop the new way to share information among CFSC team. This chapter proposes the framework of Integrated Wireless Site (IWS) which is a wireless system based on Wi-Fi technology that cover the entire job site and link various devices and equipments together. The system is purposed as an information logistics model in order to reduce waste and add value.

3.1 Information Logistics for Construction

Information Logistics for construction (ILC) can be defined as “the process that plans, implements, and controls the flow of information along the path when it is created, transferred, used, stored and reused for the length of entire life cycle of the construction project.” The flow model of ILC is presented in figure 3.1. Traditionally, a construction
project begins when there is a need for a new facility. Then the process evolves from concept design to detail design, construction and deliver to the customer. Based on extended logistics concept, however, the life cycle of the project has been extended to include service life of the facility (used) and demolition process when the facility is no longer needed.

At the same time when the project life cycle starts, the related information logistics begins. The customer’s need is identified and delivered to the design team. The designers use the information created by the customer (in this case, the owner of the facility) as a resource to create construction drawings. In addition to the owner’s need, the designers also need “expertise” and other sources of information such as state.
regulations, design standard and information from past projects. The designers use these information and other resources to create output (e.g. design drawing) which by itself is considered information that needs to be passed to the contractor. The idea of ILC is to design and implement a system that controls the flow of information, in order to ensure that the right person (or machine) has the right information at the right time. This can happen in two different ways. First, if the person knows what information he needs and when he needs it, the system should be implemented in a way that he knows where to find it and how to get it. The system, then, must allow him to “pull” such information whenever he wants. The second is considered as “push” method. When the information is created, either the person who creates the information or the system must be able to identify who should receive the message and when they should get it. The system then pushes the message or alerts the recipients.

Figure 3.2 shows typical information flow model in a construction project. Each company’s representative is a member in CFSC team. The information that flows between team members is considered horizontal. At the same time, each company’s representative also needs to communicate with his superior and subordinate. The contractor’s superintendent, for example, after has a meeting with the owner and designers will need to tell his foreman what to do and if there is any change in contract he will have to tell his boss and the accounting personnel as well. The flow of information in this direction is called vertical.
Typically, the information flow must be either horizontal or vertical. The owner and designers usually do not call the contractor’s accounting personnel directly without acknowledgment of the contractor’s project superintendent. Similarly, if the contractor’s purchasing wants to know about work quantity change due to change order, he will need to get that information from the company’s representative who is a CFSC member. This flow structure, while considered necessary, has caused delay in the flow and inconsistency of the information.
3.2 Integrated Wireless Site (IWS)

Same as rail road and aviation revolved physical logistics, the Internet and emerging technology like Wi-Fi have revolved the aspect of information logistics. To overcome the limitation of traditional flow discussed earlier, the concept of Integrated Wireless Site System (IWS) is presented. The objective of IWS is to provide instant access of authorized information to authorized entities. The authorized entities can be either a person and/or equipment. Due to the fact that not all CFSC members are full-time onsite, the system needs to be easily accessed from any remote locations. The Internet is a perfect way to provide such ability.

The key components of IWS are the wireless network at construction site that allows people and machine to share information with each other in real-time and the centralized information control system with distribution ability to decentralized entities. As shown in figure 3.3, the flow structure of a construction project that implements IWS, in contrast to the one shown in figure 3.2, uses IWS as an interaction point among CFSC team. IWS allows authorized person outside CFSC team to access certain information such as the status of drawing, change order, RFI (request for information) including work progress and site condition directly whenever and from wherever they want. This will reduce distortion of the information caused by communication through an intermediary.
However, ability to send information to the system from person outside the team should be limited and carefully defined due to security and accuracy of information.

![Diagram showing information flow structure of IWS](image)

*Figure 3.3 Information flow structure of IWS*

In term of planning and control, IWS provides an opportunity to integrate planning and control functions at different level. Figure 3.4 shows function breakdown of typical construction organization. Part of this model is based on a general breakdown structure presented by Bernold et al. (1990). The planning and control functions at each
level, which are used to be separate functions, can be more integrated and/or synchronized. The managers at higher level can use lower level information such as site condition and equipment status which are accessible in real-time to effectively plan and control. The information that normally available at one level now can be effectively shared with different level both intra-organization and inter-organization.

Figure 3.4 Extended functional breakdown of construction
3.3. Conceptual Framework and Uses

It is important to note that the IWS is not intent to eliminate the interaction between team members; rather it serves as a tool that streamlines the flow of information and allows people and/or machine to communicate with each other in real-time. In the simple word, the IWS is a wireless network that covers the entire site, allows any network devices such as network camera, water detector, humidity and temperature monitoring devices or even construction equipment such as crane and forklift to communicate to each other and provides accessibility to all authorized person in the CFSC team. The conceptual diagram of IWS is shown in figure 3.5. Network communication of large equipments in construction can have many different goals. One example is to detect an unsafe status of equipment while in operation. Bernold et al. (1997) developed such a system for cranes called the “BlackBox”. The intelligent monitoring system can be used to retrofit existing crane hardware. The simple architecture and the transportability of the sensors provide opportunities for utilizing the concept for other types of cranes or even for other machinery where unsafe conditions cannot be detected easily by an operator. The BlackBox mounted on a crane can be integrated into the IWS to wirelessly alert people or establish communication with other equipments in the network automatically. In addition, such information can be maintained in the server computer and be used as a historical record for the equipment.
Since equipment, material and labor are key resources on a building site, tracking their whereabouts is essential. The RFID (Radio Frequency IDentification) tag technology has successfully been used in the retail and service industries. For example, Wal-Mart and FedEx have implemented RFID tags to improve their supply-chain and logistics management. By integrated RFID technology into the system, the IWS will be
able to track and identify materials, equipment, tools, and other resources automatically and immediately after they passed the gate.

The IWS can also be used as a site monitoring system. The system includes digital imaging devices such as digital cameras and video cameras that upload real-time images and video clips to the central hub. With the IWS, project participants can monitor the construction progress from another city or anywhere in the world. The images, then, is kept as a project history. Typically a camera is located so that its field of view covers some point of interest. This could also help to resolve claims and dispute. For large project built in downtown area, the uninterrupted supply of some material such as ready-mix concrete is vital. Video cameras can also be used to control the supply of ready-mix concrete by provide real-time images of work face and concrete plant. The plant manager can control the quantity of concrete to be delivered according to the work face situation. In addition, video camera can be used to control material staging area to make sure that the suppliers have put materials at the right place and the same camera can serve as a security device prevent material from get stolen.

Some robotic applications use a video camera to provide vision-based controlled system. In figure 3.6, a video camera has been attached to the arm of the Robotic Bridge Paint Removal (RBPR) system that was developed in the Construction Automation and Robotics Laboratory (CARL) at North Carolina State University. The video camera allows workers to work at a safe distance and avoid hazardous environment.
Video conferencing is one of the main emerging communication technologies. The use of video conferencing over the Internet is expected to grow with the increasing network transmission speed and bandwidth. In addition, research has shown that, in many cases, video conferencing is as effective as face to face in group-problem-solving (Attia, 2002). With today’s advance in wireless communication, discussion and request for information can be done real-time from the work face. By using IWS, construction workers will be able to send real-time video from the work face via wireless transmission to the receiver in the site office. Then the signal can be transferred to the computer and sent to remote computer via the Internet.
3.4 IWS as a Tool for Adding Team’s Value

Webster dictionary (1994) provides more than ten definitions for the word “value.” For instance, 1) “a fair or proper equivalent in money, commodities, etc., esp. for something sold or exchanged; fair price or return” 2) “the worth of a thing in money or goods at a certain time; market price” or 3) “estimated or appraised worth or price; valuation.” A fundamental problem in a general theory of value is to define value so as to include all its forms. Value is specific to individuals. It depends on a person’s relative needs for security, pleasure, peer approval, aspirations, etc. (Hicks, 1994). Adam Smith, a Scottish philosopher and economist, described the meaning of the word “value” in his famous book “The Wealth of Nation” as follow (Smart, 1931):

“The word ‘Value’, it is to be observed, has two different meanings, and sometimes express the utility of some particular object, and sometimes the power of purchasing other goods which the possession of that object conveys. The one may be called ‘value in use’; the other, ‘value in exchange.’ The things, which have the greatest value in use, have frequently little or no value in exchange; and on the contrary, those, which have the greatest value in exchange, have frequently little or no value in use. ‘Nothing is more useful than water: but it will purchase scarce any thing; scarce any thing can be had in exchange for it. A diamond, on the contrary, has scarce any value in use; but a very great quantity of other goods may frequently be had in exchange for it.’

Despite the confusion of the definitions, the word “value” has been used extensively in economic, business, and engineering management. “Value Engineering” is a widely used method to improve product value by improving the relationship between the product’s functions and its cost (Maynard, 1971). In supply chain management,
“customer’s value” usually defined as performance’s satisfaction at the lowest possible cost. From these definitions, it is clear that the word value has more meaning than just monetary value. For this research, value is defined as anything that increase people’s satisfaction. This includes usefulness and self-esteem. Value is specific to individual and the willingness to acquire that value is determined by its cost.

Working in an inter-organization environment like the one in CFSC team requires new perspective of goals. Clearly, each team member is a firm’s representative and must work to make sure that his/her firm get the most value as possible. However, maximizing one firm’s value does not mean that the overall value is maximized. Research has shown that, through collaboration, an increasing in overall value can be achieved and only by sharing the gain value so each firm can get more benefit (more details is presented in section 3.5). The IWS is designed to increase overall value by encouraging collaboration among team member. The way IWS adds value to the team is to minimizing waste in the system and creating new value for the team member.

3.4.1 Extended Construction Waste Concepts Based on Lean Thinking

There are several kinds of wastes in construction process. The most common waste recognized by construction managers is physical waste such as debris from packaging and leftover from used material as shown in figure 3.7. Some waste such as energy leak can be considered physical waste even it is difficult to physically detect.
Some of physical waste might not have any value left (Fig. 3.7 a.) but have to be eliminated in order to complete the process.

Figure 3.7 Physical waste

Figure 3.7 b. shows physical waste that still have some value, in the other words, it can be sold or used. This kind of physical waste needs to be carefully managed. For example, some companies allow site manager to manage the money from selling unusable rebar left after the full-length rebar has been cut. Many managers use the money to benefit workers at the site. This can, in turn, encourage workers to create more unusable rebar. This physical waste is common and can be found in every construction site. However, physical waste is just a tip of an iceberg. There are much more waste based on lean thinking. As describe in section 2.4, there are 7 types of waste based on Ohno’s muda plus one added by Womack and Jones. These wastes are summarized as follow: 1) Over production, 2) Waiting, 3) Transportation, 4) Too much machining (over processing), 5) Inventory, 6) Moving, 7) Making defective parts and products, and 8)
Design of goods and services which do not meet users’ needs. Although these “lean thinking wastes” are identified based on manufacturing process, most of them, if not all, can also be applied into any business process including construction. Lean thinking waste focus on the activity that only consumes resource but does not added any value. These non value-added activities occur at every stage of the process. In figure 3.8 (a), the cement bags need to be moved around the site because they are not put at the right place when delivered. This unnecessary transportation does not add any value to the process or anyone; therefore, it should be eliminated as much as possible. This type of waste is usually overlooked by the manager because it is non-physical and intangible.

![Transportation waste](image)

![Waste from correction](image)

(a) Transportation waste  (b) Waste from correction

Figure 3.8 Non value-added activities

Many non value-added activities are caused by asynchronous information flow. In figure 3.8 (b), workers are correcting a concrete slab. The level of concrete slab has been changed due to change in finishing material. However, at the time this slab was
poured, the supervisor did not get the update drawing. Therefore, the slab was poured at
the wrong level and need to be reworked. The rework process usually consumes more
time and resource than the original task itself. It does not add any value and also create
physical waste.

Figure 3.9 Components of waste in construction
Both physical waste and non value-added activity can be categorized into two types: one that can be eliminated immediately without any negative effects and another that still necessary (but can be reduced) based on current practice and culture. For instance, the on-site meeting activity does not add value to the finished product but still needed in order to coordinate and maintain relationship between project participants. The components of waste in construction site is summarized and shown in figure 3.9.

![Images of waste](image1.jpg)

(a) Over production  (b) Improperly store

Figure 3.10 Cause-and-effect of non value-added activity and physical waste

There is a link between physical waste and non value-added activity and one waste can causes another waste. For example, over-production waste, as shown in figure 3.10 (a), is caused by delay of information. When the owner’s requirements change, it may cause the architect and/or engineer to change design drawing. If the contractor does not get that information on time, it may be too late to inform the supplier about the change in quantity. The production that does not meet customer’s need is non value-added activity and once over-production waste is created, it creates physical waste. Then,
management needs to think about what to do with that physical waste. It may be discarded or it may be sold. Either way, it needs to be transported out of the site. All of these are considered more non value-added activity created by the physical waste that was created by previous non value-added activity. Similarly, improper storage of material on site as shown in figure 3.10 (b) causes the material exposed to water. The damaged materials need to be separated from good ones and properly disposed. These activities are considered non value-added.

3.4.2 Creating New Value

Elimination of waste, especially non value-added activity is one of the main focuses for this research. Any activity that does not contribute to the customer’s requirements should be eliminated as much as possible. However, the IWS framework provides an opportunity to provide more value beyond customer’s expectation. One unique function of IWS is the creation of visually or electronically generated as-built. Most of the customer including the user of the facility may not have background in construction. Communication with non-technical person by using photo-image is far more effective than confusing symbols and technical terms showed in 2-D as-built drawing, if there is one at all. Preliminary experiment compare effectiveness between 2-D drawing and photo-image is presented in chapter 5. Photo-image visual as-built also benefit contractors and other technical person as well. Historical image archive can be
used to identify problems that may occur after the process has completed. It can also be used as a training tool for inexperienced workers to learn from past projects.

As shown in Fig. 3.11 (a) and (b), spatial data about the exact location of a new water pipe can be collected from a laser positioning system. Alternatively, digital pictures allow the new homeowner to see through the walls. If the inspection of the electrical and plumbing system would include taking a series of digital pictures, an extremely useful information bank could be established. Another example of useful visual as-built is the pictorial marking of buried utilities such as water, sewer, cables, and gas. Any homeowner who has changed the landscape around his/her house could benefit from the availability of such information.

![Location of utilities before dry-wall is hanged.](image1)

![Location of water lines](image2)

Figure 3.11 Visual as-built for the homeowner
The goal of IWS is to add value by both reducing waste in construction process and creating new value for the CFSC team member. To reach this goal, the acquisition procedures and information flows need to be integrated and synchronized. In addition, every entity involved in the process must realize the important of the problems and willing to share information in order to achieve the group objective which is increasing overall value for the team. However, value is specific to individual and all team members are different. Implementing the system may benefit one member more than another. At the same time, the system may cost each member differently. The next section discusses the important of collaborative and sharing of gain value approach to make the implementation possible.

3.5 Collaborative and Share: A Win-Win Situation

CFSC team is proven to have an important role to make lean thinking success by eliminate muda and create more value. This gain value, however, has raised a question of who is justified to take. The general theory of the firm is that management’s primary goal is to maximize the value for his firm (Samuelson and Mark, 1999). Therefore each delegate in CFSC team will try to claim most of the gain value for his company or at least not lose any value. One aspect of value can be represented by cost. In a comparative field test Salim and Bernold (1994) showed that through up-stream planning, rebar could be bundled and shipped according to the way the rebar is placed. If the rebar is staged
properly, ineffective time spent on re-handling and searching can be eliminated. The result of the study showed that placement-oriented delivery and staging improved crew level productivity in the placement of rebar by 30% compared to the traditional method. Key to the productivity gain in laying the bars, however, was a supplier who was willing to collaborate with the subcontractor in shipping the steel in a way that matched how the crew was progressing. One incentive that convinces the supplier to cooperate in lean delivery is to have share in the saving that the subcontractor can make. Figure 3.12 summarizes possible alternatives of the subcontractor and the supplier in payoff matrix form. If the supplier agrees to participate in lean delivery, it will cost him $5 for spend more time rearranging the rebar. If he chooses not to participate, it will cost him nothing

<table>
<thead>
<tr>
<th>Supplier</th>
<th>Share $10</th>
<th>Not Share</th>
</tr>
</thead>
<tbody>
<tr>
<td>Do Extra-work</td>
<td>7 5</td>
<td>17 -5</td>
</tr>
<tr>
<td>Not Participate</td>
<td>-10 10</td>
<td>0 0</td>
</tr>
</tbody>
</table>

Figure 3.12 2 X 2 Value payoff matrix

The subcontractor, on the other hand, will gain $17 if implementing lean delivery by increasing his productivity. In order to convince the supplier, the subcontractor may agree to pay more or “share the value” with the supplier. Assume the subcontractor is willing to pay $10 more for the supplier’s extra-work. This will compensate the cost of
supplier and left him $5 for profit. If the supplier, however, tried to make maximum profit from the agreement by reducing his cost which may decrease the quality of service and, therefore, reduce value to the subcontractor. In long term, the subcontractor will realize and move back to his old strategy by terminating the agreement. This will bring both the supplier and subcontractor to the “equilibrium” showed as shading area in the figure. In theory of game, if the players are in equilibrium this means there is no other way to make more profit except cooperate to each other. In this case, if the supplier and subcontractor are trying to maximize their profit, the best they can do is to remain in the traditional way and gain nothing. On the other hand, if they can have agreement and establish trust between each other, the subcontractor and supplier can make $7 and $5 respectively.

Subcontractor

<table>
<thead>
<tr>
<th>Supplier</th>
<th>Share $10</th>
<th>Share $5</th>
<th>Not Share</th>
<th>Promise New Contract</th>
</tr>
</thead>
<tbody>
<tr>
<td>100% Extra-work</td>
<td>7</td>
<td>5</td>
<td>12</td>
<td>0</td>
</tr>
<tr>
<td>50% Extra-work</td>
<td>-2</td>
<td>8</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Not Participate</td>
<td>-10</td>
<td>10</td>
<td>-5</td>
<td>5</td>
</tr>
</tbody>
</table>

Figure 3.13 3 X 4 Value payoff matrix
In real world, the situation will become much more complicated especially when other factors besides direct cost such as, who dominated the supply chain (who has power), company image, long-term relationship etc. also have to be taken into consideration. Both subcontractor and supplier may have more than two alternatives. Figure 3.13 shows an example of 3X4 value payoff matrix that the supplier has three alternatives and the subcontractor has four. However, the same concept of value sharing can still be applied.

Collaboration and value sharing between contractors and suppliers or any parties among CFSC team member offers opportunities to improve productivity and cut resource waste by optimizing the use of the combined resources. Due to highly fragmented nature of the construction industry, information is being created and but not shared by many different companies. The main obstacle to sharing information freely, however, is the low-bid orientation of the industry. Each participant will hold his/her information about the process associating with their true cost and profit. The only information they are willing to share is the price tag and the only way to make additional profit is to take from others. A win-win coalition building strategy would create the necessary incentives to make the IWS an economically successful technology for each participant.
4. DEVELOPMENT OF VISUAL-BASED IWS SYSTEM (V-IWS)

In chapter 3, the framework of IWS was presented. The IWS model was proposed as an alternative to the traditional asynchronous information logistics in construction. As indicated, the goal of IWS is to share real-time information among authorized users anywhere at anytime. In order to prove this concept, a prototype system was developed. This chapter presents the development of Visual-based IWS (V-IWS) as well as rules and regulations that have to be followed.

4.1 Effectiveness of Visualization

Visualization has been recognized as an effective means of communicating new ideas and complex situations (Rad, H.N. and Khosrowshahi, F., 1997; Whyte, J., Bouchlaghem, D. and Thorpe, T. 1999; and Yuhua Luo, et al., 2002). It reduces communication difficulties for CFSC team which is comprise of parties from different disciplines. Even non-technical parties such as owners and facility users, communication using visualization is more effective than using technical drawing with special symbols. A survey of 103 construction related professionals found that the client (owner) was identified as the most likely to benefit from the visualization of proposed construction
In addition, visualization also increases productivity. A recent study showed that more media-rich communication channel, especially the one that supports visualization, would lead to higher group productivity (Attia, 2002). Visualization is also a promising tool in engineering education. A research team in the United Kingdom has studied the use of digital imagery and visualization materials to help students in the civil and building engineering curriculum improve their understanding. The initial evaluation found that students showed improvement in various areas such as increased students’ participation and motivation, decreased time required to complete exercises and improved retention of information by students (Bouchlaghem et al., 2000).

### 4.2 Sources of Visual-based Information

A preliminary study to investigate various sources of visual information has been conducted at Knightdale residential project in Raleigh, North Carolina. Spectrum Home Inc. is the general contractor. The project (Phase 1) comprised of 7 residential homes.

#### 4.2.1 Public Database and Outsourcing

The most recent visual technology in construction is the Geographic Information System (GIS) such as aerial photos, elevation contours, soils data, roads and property
information. Many public sources such as libraries and government websites provide GIS data to citizens and businesses for free or for a small fee. GIS data of the Knightdale construction site was found at Wake County’s website which maintained GIS data for the entire county (http://www.wakegov.com/county/propertyandmapping/gis.htm). The GIS database provides data such as Tax/Parcel maps, Topographic maps, 1999-Digital Orthophotographs, Soils and City of Raleigh Planimetrics. Some data, for example, Tax/Parcel files are updated monthly while some may have not been updated for more than a year old. The website provides data in both downloadable files and online viewing version. The downloadable file contains files in various file formats such as DXF, MrSid, and SHP. The user must have appropriated software to view the files. Examples of downloadable data are shown in figure 4.1 (a) and (b). The users start with the county map and then go down to specific area with the list of available files to download. The online version called iMaps is shown in figure 4.1 (c). The users can go to specific area and view the image directly from their browser such as Netscape and Microsoft Internet Explorer.

Even though the GIS data from public sources like Wake County’s website is useful, some data is consider to be out-of-dated. For instance, the aerial photo of Knightdale construction site shown in figure 4.1 (c) is considerably old. By the time this aerial photo has been retrieved from the database, seven houses were already built on the site. For construction planning and control, this aerial photo may not be useful.
Figure 4.1 Available visual information of Knightdale construction site

(http://www.wakegov.com/county/propertyandmapping/gis.htm)
4.2.2 Still Digital Photo and Video Clip

In order to get an update aerial view of the Knightdale construction site, a digital camera has been attached to a balloon as shown in figure 4.2 (a). The camera is control by a remote control to take pictures. The balloon is let go of at about 80 feet and more than 50 pictures have been taken. The picture, then, are sorted and overlaid by using a photo editor software. The result is shown in figure 4.2 (b). Even though more than 50 pictures were taken, only few pictures can be used. The balloon is hard to control because of high wind at the high attitude even though it seem to be calm on the ground. In addition, not seeing through the view finder make it’s difficult to get good composition.

(a) Field testing

(b) Pictures overlaid using computer

Figure 4.2 Balloon testing
Due to the advance in digital photography, using digital camera to take pictures of construction process is far more cost effective than using film camera. Other than the cost of digital camera, the camera can take hundreds of pictures with almost no cost per picture. In Knightdale study, digital pictures are taken from each house every week. Then the pictures are grouped by lot number and task. Every week, the pictures will be uploaded into a test website that has been established for this research project to create a visual as-built for each house. The visual as-built provides visual historical record for the owner and anyone participating in the project. At the end of the project these “photo album” can be recorded into a single CD and give to the house’s owner. An example of visual utility as-built for lot 19 is shown in figure 4.3. In addition, because these pictures are updated to the website every week, the owner and/or designers can use the website to check progress of the construction without going to the site themselves.

Figure 4.3 Visual as-built for lot 19
In addition to still digital picture, video has been proven to be an effective tool for performance improvement. Both manufacturing and construction have used video as a tool to improve productivity for more than three decades. Video cameras or camcorders take continuous pictures and generate a signal for display or recording. Two types of video signals widely used today are analog video and digital video. The video technology, like computer technology, has become more advance especially for digital video and the price has been dropped dramatically in the past 5 years.

Figure 4.4 Videotaping used in process improvement study
In this research, a two stories house has been chosen for the study of roof truss installation process. The video has been taken for the entire process. By analyzing the tape, the process can be seen as cycles. One cycle of roof truss installation process consists of 4 main tasks: T1: Attach a truss with the crane, T2: Move and set the truss into position, T3: Nailing the truss and temporary bracing, and T4: Move the crane back to attach the next truss. There are three groups of crew in the process; one group (2 workers) is on the ground attaching a truss to the crane, the second group (3 workers) is on the roof nailing and temporary bracing the trusses, there is also another worker driving the crane. Figure 4.4 shows the screen shot taken from the videotape of each task in one cycle. There are total of 13 cycles for the entire process. By watching the videotape, the manager can analyze the problems and/or inappropriate use of resources which can provide insight to process improvement. However, if the video clip will be shared via the Internet, the clip needs to be in digital format. Typical digital video (DV) files are huge. One hour of uncompress DV file can use up to 14 GB of hard disk space. Thus the DV file needs to be compressed before it can be uploaded or downloaded. The technology by which video compression is achieved is known as a "codec" (compression / decompression). Various types of codec have been developed, some of which are MPEG, Cinepak, Microsoft Video 1, and Intel Indeo.

In order to play a DV file over the Internet and ensure that it will be played at a constant, uninterrupted speed, the file needs to be sent entirely over the network to the hard disk on the user’s machine. It can then be played back from there. Even after being
compressed by codec, the file is still big (100 MB or more). Thus it is not practical for most people to wait for the download to be completed. To overcome this problem, streaming technology has been developed. Since the computer can often play back audio and video faster than it can be sent over the network, the streaming process is to give the playback a buffer. The computer quietly receives and stores enough of a broadcast so it can keep up, and then begins playing that part back while the rest of the data is received in the background. The stream video requires trading off video quality for immediacy of playback. Depend on the viewers’ connection speed, if they connect by modem, the file need to be encoded, so that it goes over that slow link, but the quality will be substantially degraded. On the other hand, if they are using better connections, the file can be encoded to increase the video quality. Three most popular streaming formats are RealNetwork's RealVideo, Microsoft's Windows Media Technologies, and Apple's QuickTime. The viewer will also need a player for the specific format. The player software is usually available for free.

Even though video has proven to be an effective tool for process improvement, the use of video technology especially for surveillance purpose has raise serious concern on personal privacy. The right of privacy is based on both constitutional law and common law (Bickel, 1999). The use of video technology in certain environment especially in public place should not be so intrusive such as focus on the letter people is reading. In construction, the technology should not be used to monitor individual’s behavior but to measure performance of the process.
4.2.3 Disadvantages of Using Video and Digital Still Camera

Although using of video and digital camera in construction project is proven to be cost effective today, it still has some drawbacks. First, while digital still picture is ready to transfer via the Internet, typical video clip is not. To transfer a video clip via the Internet, the clip needs to be in digital format. As mention earlier that typical DV files are huge. These files need to be either compressed or streaming or both. However, these processes are complicated, especially for novice to ensure acceptable video quality. Second, the images from video and digital camera cannot be available on the web in real-time. Even though the images can be updated on daily basis, they are still far from real-time. Update more than once a day is just not practical. Finally, the process of update images into the web is not automated. This means somebody needs to be assigned to do the work on a regular basis. Manually update the images into the website is time consuming and prone to human error.

4.3 V-IWS System Design

In order to utilize the benefit of visual information, the new approach of getting visual information needs to be developed. Based on conceptual framework of the IWS presented in chapter 3, this section describes the visual-based IWS prototypical system
called V-IWS. The system provides real-time access of photo images of construction site. The system can also be used as an automatic surveillance at night if connected to a motion detector and light source. The images are updated to the website automatically. Therefore, every project participant with the Internet access can get visual information used for decision making and rapid problem-solving from anywhere at anytime.

4.3.1 System Components

The core of the system is a wireless local area network (WLAN) using Wi-Fi standard that covers the entire construction site. A WLAN is a cellular computer network that transmits and receives data by using radio signal instead of wires. Technologies used in WLAN are rapidly changed. Wi-Fi technology which is considered standard today did not even exist ten years ago. As described in section 2.6.4, Wi-Fi is a radio-based networks technology that connects computers or wireless devices compatible with Institute of Electrical and Electronic Engineers (IEEE) 802.11x standards. 802.11b standard, which is one of the most widely use Wi-Fi standards, was finalized and approved by IEEE in September 1999 (The Wireless LAN Association, http://www.wlana.org). 802.11b allows data to be transferred at speed up to 11 Mbps. Some 802.11b product, for example D-Link DI-614+ which is used in this research, may have special mode that allows data transfer speed up to 22 Mbps when used with the some specific products, usually from the same company.
Wi-Fi network consists of a centrally located device called “access point.” Each computer or network device within the network will need a small device called “client adapter.” A client adapter must transmit data to the access point, which then relays it to another client adapter to which the data is addressed. Even though some companies that produce 802.11b devices claim that the devices can transmit data up to 1,000 feet outdoors, typical distance that the data can be effectively transfer is around 100 to 300 feet depending on obstacles and interference. In order to connect Wi-Fi network to the Internet, the Wi-Fi network will also need a device called “router.” A router is a device that connects one network to another network, in this case Wi-Fi network to the Internet. Today, many routers can also be used as an access point. The V-IWS uses Wi-Fi network to link between network devices, in this case, three network cameras and a central computer. The central computer contains project database and also serve as web server and file server. The network cameras, each of which has its own IP address, provide real-time visual access to anywhere in the site. The pictures also are saved as historical records or used for process analysis, other devices such as temperature and humidity sensors can also be added to the system if needed. A network camera is different from typical digital camera and web cam because it has built-in network device that can communicate with a server or other network devices without the need of computer.

The component diagram of the V-IWS is shown in figure 4.5. Users of the system can be classified as general internet users and project users. Access of the
information in the system is controlled by user name and password. Only authorized person can have access or updated certain information. Another advantage of using web technology is that the system can be integrated into another system or link to a device in another network. For instance, the V-IWS users can have access to the network camera at the factory of engineered material being prefabricated in different locations around the world to synchronize with works at the construction site.

---

Figure 4.5 Components of the V-IWS
The project database saved in the central computer serves as an information center where CFSC team members can have access to any information they need for their tasks. The database is a relational database developed by using Microsoft Access. MS Access is a Database Management System (DBMS) that supports Open Database Connectivity (ODBC) standard. ODBC allows any data in the DBMS that supports its standard to be accessed by other applications or web servers. Active Server Page (ASP) technology is used to enable users to interface with the data kept in the project database. ASP is a server-side script technology used to create dynamic webpages. ASP allows static HTML code to be mixed with programmatically scripting languages such as VBScript or JavaScript. An example of ASP codes used to check username and password before the user can get to the restricted area is shown in Appendix C. By using ASP, Structured Query Language or SQL can be used to retrieve, insert, or delete data in the project database. The suppliers can post their schedule for material delivery on the online material-planning page. The information, then, will be saved into the database in real-time. Online message board allows team members to leave messages or post announcements to other members. The message saved in the online message board can also be used as tracking record or project log.

4.3.2 Regulation and Security Consideration

Implementing Wi-Fi network is subject to various regulations. The regulations are intended to minimize the interference between the users of radio equipment operated
in unlicensed bands. These rule and requirements vary from one country to another. In
the United States, Wi-Fi is governed by Part 15 of Title 47 of the Code of Federal
Regulations, informally known as “Part 15”, imposed by the Federal Communications
Commission or “FCC” (Duntemann, 2003). Parts of the FCC regulation on Wireless
Communication are shown in Appendix A. Wi-Fi devices sold in the market are subject
to equipment certification to ensure regulation compliance such as operating frequencies
and power levels. Therefore, using “off-the-shelf” Wi-Fi equipment unmodified is
considered comply with the regulations. However expanding the coverage distance by
changing or modifying the antenna, one needs to make sure that the transmitter output
power is not excess 1 watt limited by FCC.

In addition to FCC regulations, implementing Wi-Fi network must comply with
local regulations as well. In this research, the network is implemented on North Carolina
State University campus. Therefore, it must comply with the University policies and
procedures governed by Communication Technologies and Information Technology
Division (ComTech). Rules for implementation of wireless networks at NC State are
shown in Appendix B. NC State has its own wireless network which is part of a campus-
wide Nomad Computing Environment. Implementation of the V-IWS or any WLAN
must be done so that it does not interfere with the University network.

Security is also an essential consideration when implementing WLAN network.
Even though there is no completely secure network, whether it is wire or wireless,
security measures such as access control, authentication and encryption should be employed. According to NC State rules, all transmitters (access point) of any private network must be registered with the university and configured to allow only known client Media Access Control (MAC) addresses to use the network.
5. SYSTEM IMPLEMENTATION

The V-IWS is designed to be a real-time information sharing network. Unlike finished building, it is not practical to implement wired network in construction site. Site condition and the nature of construction process require the network devices used in the system to be moved around as the project progress. Therefore, using wireless local area network technology such as Wi-Fi is crucial. Nevertheless, implementation of the V-IWS in construction project still has another challenge. Most construction site, especially small to medium size project, does not have high speed broadband Internet access available on site. This chapter describes the implementation of the V-IWS. The system requires one Internet access point and secure location for the server computer. Due to its location, the USTL construction site on NC State campus provides perfect conditions for implementing the system.

5.1 USTL Project Overview

The Undergraduate Science Teaching Lab (USTL) project is located on NC State main campus, around 1,400 feet from Mann Hall Building where the router and the system server located. The project consists of the construction of 70,700 gross sf. of
instructional laboratories and classrooms for chemistry/physics. Along with the construction of 40,500 gross sqf. of instructional laboratories, classrooms and greenhouses for horticultural sciences. The building has three stories with basement plus three greenhouses. The contract is single prime and R.N. Rouse is the general contractor.

5.2 System Installation

An under construction building, unlike finished building, does not have an Internet access. Therefore long-range wireless transmission is crucial. In this research, the Wi-Fi network at the USTL site is connected to the Internet access point in Mann Hall Building about 1,400 feet away. Two external high gain antennas and one repeater are used to extend the coverage area. As shown in figure 5.1 (a), the router with Internet access and the server computer are located on the first floor of Mann Hall Building. With the external antenna on the roof, the wireless signal is sent to the repeater with the second high-gain antenna on the roof of Garner Addition Building as shown in figure 5.1 (b). The repeater, then, creates a Wi-Fi network that covers the USTL construction site. In some area of the USTL building such as basement or behind concrete wall, an additional repeater may be needed.
(a) System’s layout

(b) The repeater with high-gain antenna

(c) Internal mobile camera

Figure 5.1 V-IWS installations (Aerial photo from MapQuest.com)
The appropriate number of network camera used in the system is based on size of the project and needs of the CFSC member. In this research, three network cameras are used; each of them has their own IP address. One wired network camera is put on the roof of Garner Addition to provide an overall view of the construction site. This camera is connected to a separate internet access point in the building; therefore it serves as an external link to the system. Other two network cameras are connected wirelessly to the repeater on the roof of Garner Building and are assigned IP addresses by the router in Mann Hall. These two wireless cameras are used only by authorized person and can be installed anywhere within wireless coverage area. The users who want to see real-time pictures from these two cameras must login to the system with the username and password assigned by the system administrator.

These three network camera, together, provide real-time images of any area in the construction site that can be used as a planning and control tool for particular process. Figure 5.2 shows samples of the picture from the network cameras before and during sheetrock delivery process. Figure 5.2 (a) shows north side of the USTL building. The picture was taken from the camera on the roof of Garner Hall Building the day before sheetrock was scheduled to be delivered. Figure 5.2 (b) shows south side of the building taken from the roof of Garner Addition Building on the delivery day; the white truck in the circle was a delivery truck. Figure 5.2 (c) and (d) were taken by a mobile camera unit inside the building showed the delivery process and staging area.
The cameras capture and upload pictures to the server. The time interval can be set from 1/10 second per frame to 1 frame per week. However, very short interval time will require very strong connection (fast throughput). In this research, the cameras are set to upload one picture per 15 minutes. It also shows that the interval time shorter than one picture per every 30 second is not practical in the field. Nevertheless, one can still
see live motion video by using streaming feature supported by the cameras. Another factor that needs to be considered when selecting the interval time, is hard disk space. By setting one picture per minute at 14 hours a day, it may use hard disk space up to 50 MB per day per camera.

5.3 The Effects of Construction Site Environment on the System

Wi-Fi network uses radio signal to transmit data between access point and client. This signal loses strength when the distance is farther, encountering nature and manmade obstacles, or in a situation that there are a lot of background radio frequency noise. Even though Wi-Fi network has been proven to work well in typical finished building, there is no known case that the technology has been tested in construction site where there are a lot of construction machines and equipment that can cause interference with the signal. Determination of the exact number of signal and data package lost requires specialty experts and equipment that go beyond the scope of this research. The objective of this section is to verify that whether or not Wi-Fi network provides acceptable data transfer rate when implementing in a construction site environment where construction machines and equipment are operated.
5.3.1 Field Signal Measurement

It has been known that distance, obstacles, and RF background noise can cause attenuation (a reduction of signal strength during transmission). The rules of thumb of how to reduce attenuation and maximizing transmit range can be found in any Wi-Fi product manual. For instance, the product manual of the D-Link AirPlus DI614+ which is the router used in this research provides general guidelines to maximize range as follow. The number of wall, ceiling, and any obstacles between the access point and the receiving devices should be minimized. The building material of the obstacle and the direct line between the access point and the receiving devices also has different effects on the attenuation. For example, 1 foot thick wall at 45-degree angle will have similar effect as a 1.4 thick wall. Metal and brick wall cause more attenuation than drywall. In addition, any Wi-Fi devices should be kept away from any electrical devices that generate RF noise such as generator, microwave, and wireless phone.

Despite following the general guidelines to minimize attenuation, it’s still very difficult to predict the field intensity and the presence of interfering signals without a testing device. In order to fully understand the behavior of radio wave within the USTL construction site especially inside the under-construction building, a RF site survey of field signal is performed. Figure 5.3 shows the 3rd floor plan of the USTL building. The
signal is measured at 52 locations according to the building grid-line. The columns and walls shown in the figure are reinforcing concrete.

Figure 5.3 Floor plan of the USTL building (the numbers indicate the locations that signal strength and link quality are measured).

A laptop computer with 2.4 GHz wireless cardbus adapter and its bundle software have been used as the testing device to measure signal strength and signal quality at each location. The laptop and software used are shown in figure 5.4. The signal strength is a measure of the dB level of the actual signal which determines how strong the signal is.
The link quality indicates the signal to RF background noise levels which determine how clear the signal is. Lower the link quality level means higher packets loss during transmission.

Figure 5.4 Measurement of signal strength and link quality inside the building

In order to ensure that the Wi-Fi network covers most of the construction site inside and outside building, the field signal measurement has been performed under two scenarios. First, the signal is measured at each point without the repeater 2 (RP-2) shown in figure 5.3. In this scenario, the signal read by the laptop computer is the signal between the laptop and the repeater 1 (RP-1) on the roof of Garner Addition Building shown in figure 5.1. The second scenario is to add one more repeater (RP-2) at the location shown in figure 5.3 to repeat the signal from RP-1. In each scenario, both signal strength and link quality are measured at each location for around 1 minute to find the
high and low value of both signal strength and link quality for each location. The part data is shown in appendix D.

5.3.2 Wireless Field Intensity

In order to have a good connection, both signal strength and link quality should be at the high level. The level is indicated as percentage from 0% to 100%. There are no known standard of the percentage range indicating acceptable connection. Some manufacturer roughly indicates signal as good, moderate or poor connection. In this research, the signal at each location is measured for 1 minute. The high and low of signal strength and link quality between repeaters and the laptop within 1 minute interval time are recorded.

In the first scenario, the signal was measured between the laptop and the RP-1 on the roof of Garner Addition Building around 150 feet south-east of the USTL building. The measurement was done in the afternoon of typical working day with fair sky. There were one backhoe and one bulldozer working in the area between the USTL building and RP-1. There were a few crews with small tools working on the 3rd floor during the measurement. There also was one microwave oven on the 3rd floor for the crews.
Figure 5.5 (a) Signal strength from RP-1
Figure 5.5 (b) Link quality from RP-1
The results of all 52 locations are shown in figure 5.5 (a) and (b). Overall, there are smaller variations in the signal strength compared to link quality. This means while the strength of the radio signal is considered stable, the levels of packet losses vary due to background RF noise. Nevertheless, there still are continuous connections between RP-1 to the laptop at point 1\textsuperscript{st} to 26\textsuperscript{th} except point 18\textsuperscript{th}, 19\textsuperscript{th}, and 20\textsuperscript{th}. There are no connections beyond point 27\textsuperscript{th}.

Figure 5.6 Field intensity from RP-1 (Garner Addition’s roof)
From these data, the field intensity inside USTL building can be plotted by using average value between low and high of both signal strength and link quality. The signal degradation between two points is assumed to be linear. The intensity is divided into 4 zones: 1) If both signal strength and link quality is higher than 70%, it is considered “good connection” 2) Signal strength between 40% to 70% and the link quality greater than 30% is “moderate connection” 3) Signal strength between 10% to 40% and link quality greater than 10% is “poor connection” and 4) Signal strength and link quality lower than 10% is considered “no connection.” The result of field intensity from RP-1 is shown in figure 5.6. Without additional repeater, the wireless coverage is barely going beyond grid line 4. In fact, to have adequate throughput (actual speed of transferring information between the access point and network device) the network devices should be placed within “good” or “moderate” connection zone. From the figure 5.6, there is no good connection zone inside the building and there is only small area near edge of the building (grid line 6) that is in moderate connection zone. It is clear that to have more coverage area inside the building, additional repeater is need.

In the second scenario, additional repeater (RP-2) is placed within the moderate connection zone to repeat the signal from RP-1. The same measurement procedure is performed. The results of signal strength and link quality with the RP-2 at all 52 points are shown in figure 5.7 (a) and (b).
Figure 5.7 (a) Signal strength from RP-2
Figure 5.7 (b) Link quality from RP-2
Figure 5.8 shows the filed intensity inside USTL building when adding RP-2. With one additional repeater, the coverage area of Wi-Fi network is extended to cover more than half of the floor. In fact, most of the areas can have connection except inside two stair core at grid line 2. However, additional repeaters can be added to cover the area inside the stair cores.

Figure 5.8 Field intensity from RP-2
From these results, it is clear that Wi-Fi network can work in the construction. Even though concrete wall can decrease the strength of the signal, additional repeaters can be used to extend the coverage area to almost everywhere in the typical building even in the basement or stair core.

5.4 Interference According to Location of the Devices

Even though it is clear that Wi-Fi network can work in construction site, the variation in link quality proves that location of wireless network devices can have great effects on the overall connection quality. According to the protocol used in Wi-Fi networking, the information transmitted between two devices is divided into small piece called packet. Poor link quality means that more packets are loss during transmission.

Figure 5.9 Network camera on the roof of Garner Hall building
The location of the router and the repeater(s) need to be carefully selected because some machines such as a big motor, microwave or other devices that generate radio frequency can interfere and affect the link quality of the network. 2.4 GHz wireless phones, for example, can cause most interference with the Wi-Fi network used in this research which is also used 2.4 GHz radio frequency to transmit data. Other wireless LANs are another sources of RF interference. During the measurement of the signal, there were others 3 to 4 wireless LANs detected by the laptop. The RF from these networks has caused some interference with the V-IWS signal. In addition, any metal objects near the devices also cause signal loss. At the beginning of this research, one wireless network camera was located at the roof of Garner Hall Building around 200 feet north of Garner Addition where the RP-1 located. The location of the camera is shown in figure 5.9. The link quality at this location varied from 0% to 85%. Big variation at this location was caused by close proximity of the equipment and metal objects nearby seen in the figure. In addition, there is a possibility that the wireless system can also be interfered by others wireless network. The longer the wireless ranges, the higher the interference. In this particular case, there was interference from up to 5 different wireless networks on the system that had coverage radius of around 1,700 feet from Mann Hall Building. An appropriate procedure according to rules and regulations need to be strictly followed.
6. ON-SITE DATA COLLECTION AND ANALYSIS

The V-IWS is designed to increase project communication efficiency which is the main factor contributed to project success (as point out in section 1.2). The goals of the V-IWS are to eliminate non value-added activities and increase customer’s satisfaction. Based on the technologies used to build the system, the system is extremely flexible and expandable. Therefore, it is very difficult to test every aspect and/or every feature of the system. However, it is decided to test the core system and its main feature in order to validate the conceptual model. The aim of the research described in this chapter is to apply the V-IWS prototype system to a typical construction project and assess its effects on waste reduction and CFSC team’s satisfactions.

The V-IWS is implemented at Undergraduate Science Teaching Lab (USTL) project on NC State Campus. The process of case study validation has been done in two parts. First, face-to-face on site meetings are observed and analyzed to find the pattern and type of the information that flow among CFSC team. The pros and cons of on site meeting compare to using the V-IWS are discussed. Second, the effects of the system on waste reduction and CFSC team’s satisfactions are evaluated.
6.1 Effects of the V-IWS on Information Flow

As described in section 2.2 and 2.3, a CFSC team consists of participants representing different companies or organizations. In order to have a successful project, each member in the CFSC team must have an effective communication channel to share information with others. For instance, the owner and/or the users of the facility must tell the designers what they want. The designers then have to verify whether it is possible to meet that demand according to law, regulations, or technical constraint. Then the general contractor will have to be informed of what is changed and then share this information with its subcontractors. This communication network has to be maintained at every stage of the process from concept design to the completion of the project. One of the major channels the CFSC team members use to coordinate and share information is face-to-face onsite meetings. These meetings are held regularly at the job site, weekly and/or monthly. Even though these meetings are considered the effective way to communicate, they are costly, time consuming and delayed. According to the MCI conferencing paper (1998), meetings consume most of the managers’ time and cause tremendous stress. An average cost for five-person meeting is $5,197.50 (involving plane travel for four of the attendees). The study also reveals that 37 percent of employee time is spent in meetings. In order to find the way to improve CFSC team performance, it is important to understand the types and pattern of information that flow in these meetings.
6.1.1 Observation of CFSC Team Meetings

Two types of meetings were studied. The first was weekly meeting between the owner, the general contractor and subcontractors. This meeting is held every Monday morning. The number of attendees varies but usually around 4 to 7 people. Most of the attendees work fulltime on site except the owner and some subcontractors. The meeting usually lasts 45 minutes to one and a half hour. The second meeting studied in this research is Monthly meeting. This meeting is considered full team meeting of the delegates from every party including the owner (NC State), the users of the building (the professors who will be using the building), the designers (architects and engineers), the general contractor, the subcontractors, and the greenhouses’ supplier and subcontractor whose office is in Horse Shoe south of Asheville around 260 miles away. There are around 20 people in this meeting. The meeting is held on the second Thursday of every month and usually lasts 1 to 3 hours.

The data used in this analysis are collected by two means. First, 36 weekly meeting minutes conducted by the general contractor and 5 monthly meeting minutes conducted by the architect are collected. Second, the researcher has permission to observe both weekly and monthly meeting in order to get a hand-on experience of what is going on in the meeting room. The analysis of the data is described in the next section.
6.1.2 Analysis of Information Flow Based on Minutes

The analysis is based on who send the messages and what are the types of the messages being send. The messages in each meeting minutes are analyzed piece by piece and classified into 11 categories represented by code T1 to T11. The descriptions and explanations of each code are shown in Table 6.1.

Table 6.1 Information code description

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>Progress Report</td>
<td>Report what had been done in the past (progress)</td>
</tr>
<tr>
<td>T2</td>
<td>Look-ahead Plan</td>
<td>Inform what will be done in the near future (next week or next month)</td>
</tr>
<tr>
<td>T3</td>
<td>Warning / Upcoming Concern</td>
<td>Warning for upcoming event that may effects the work such as weather condition and start of new semester</td>
</tr>
<tr>
<td>T4</td>
<td>Change of Condition</td>
<td>Change of unforeseen issues such as underground obstacles and change in regulations</td>
</tr>
<tr>
<td>T5</td>
<td>Change of Requirement</td>
<td>Change of owner and/or users' requirements from the original plan</td>
</tr>
<tr>
<td>T6</td>
<td>Clarification</td>
<td>Clarification of conflicts in drawings and/or specifications</td>
</tr>
<tr>
<td>T7</td>
<td>Confirmation</td>
<td>Confirmation of previous informal information</td>
</tr>
<tr>
<td>T8</td>
<td>RFI</td>
<td>Request for more information on any issues</td>
</tr>
<tr>
<td>T9</td>
<td>Reminder / Expedite</td>
<td>Reminder of general agreement such as safety rule and work milestones</td>
</tr>
<tr>
<td>T10</td>
<td>For Record</td>
<td>Record of important issues that previously agreed outside the meeting room into the meeting minutes</td>
</tr>
<tr>
<td>T11</td>
<td>FYI / Event / Miscellaneous</td>
<td>Miscellaneous issues just for your information</td>
</tr>
</tbody>
</table>
All 41 meeting minutes have been analyzed and recorded into the information flow analysis form (appendix E). The results are shown in figure 6.1. According to the types and pattern of the information send in weekly meetings, the meeting focused on coordination between the general contractor and its subcontractors. In weekly meetings, progress report and look-ahead plan account for 47% of all information sharing in the meeting room. In contrast, monthly meetings are focused on clarification of unclear drawings, specification, and etc. Another major type of information both in weekly and monthly meetings is reminder of general agreement such as safety rule and work milestones. Most of these messages are repeated messages. For example, most of weekly meetings show that the general contractor underlines the important of safety on the jobsite by reminding all subcontractors to use hardhat and safety glasses.

Another finding is that in weekly meetings, the general contractor has a major role as the conductor of the meetings. Most of the messages are from the general contractor. The subcontractors mostly either responds to the general contractor’s questions or raise issues specifically relating to their work. On the other hand, monthly meetings are conducted by the architect as a construction administrator. However, majority of the messages are dominated by the architect, the owner, and the general contractor. Other attendees such as the facility’s users, the subcontractors, and the suppliers largely receive messages from those three members and respond or giving comments when there is an issue related to them.
Figure 6.1 Percent of information transferred in the USTL’s meetings
In addition to the types of information shared in the meeting room, the functions of the attendee associated with message were also studied. Generally, people involved in communication must act as either a sender or a receiver. There may be other purposes such as social or human relation, but that is outside the scope of this research. In the meeting room environment, it can be assumed that every attendee must act as a receiver when a message has been sent by a sender. When the sender sends a message, the act of sending a message can be categorized as: 1) inform or comment, 2) question or request for more information, and 3) answer or respond to the question or comment. Each of these functions has its own characteristic. When the senders inform or comment on issues, they may or may not expect any response from other attendees. On the other hand, if the sent message is a question, they do expect an answer. In the third category, the senders will answer or respond only when they are triggered by the questions and/or comments from other attendees.

Table 6.2 Messages classified by functions

<table>
<thead>
<tr>
<th>Meeting Types</th>
<th>Number of Minutes</th>
<th>Number of Messages</th>
<th>Functions of Senders</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Inform / Comment</td>
</tr>
<tr>
<td>Weekly</td>
<td>36</td>
<td>303</td>
<td>88.78%</td>
</tr>
<tr>
<td>Monthly</td>
<td>5</td>
<td>222</td>
<td>63.06%</td>
</tr>
</tbody>
</table>
Table 6.2 shows the messages sent by the meetings’ attendees. Based on 36 weekly meeting minutes used in this analysis, the senders inform or comment more than 80% of the times. Only around 7% of the messages in weekly meetings are questions. There are fewer answers than questions. This can be implied that some questions did not get immediate answers in the meeting room. The pattern of monthly meetings shown in Table 6.2 is consistent with the weekly meetings except more questions (as percentage) have been asked in the monthly meeting than in the weekly meetings. Compare between weekly and monthly meetings, the weekly meeting is where the general contractor and the subcontractors come to coordinate short term plan. The monthly meeting, on the other hand, is where all project participants come to make sure that all problems and vague information such as conflict between architectural drawing and structural drawing has been solved and cleared ahead of time.

6.1.3 Effects of the V-IWS on Face-to-Face Onsite Meeting

The results of the analysis describes in previous section suggest that most of the attendees, except the conductors of each meeting, spend more than half of the time in the meeting room receiving information such as progress report and look-ahead plan. This information, by its nature, does not need immediate response. Therefore, it is possible to put this information into the V-IWS in real-time rather than wait until the next meeting. This will immediately reduce the meeting time by half. However, the real benefit of using V-IWS is to make the information available in real-time. Team member can have
access to shared information 24/7 from any location. The delay of information, then, can be reduced to days instead of a week or a month.

From figure 6.1, more than 20% of the issues discussed in monthly meetings are clarification. These issues include conflict between drawings / specifications (architect, structure, and HVAC) and CAD interference between different work processes. These issues must be solved before the works can proceed. For example, after integrate HVAC CAD drawing with the electrical drawing and sprinkler system drawing; it was found that some water pipe might be set at the same level with the electrical line and/or air duct. Some of the issues are functionality interference such as the cabinet designed by the architect blocked access to the power outlet designed by the electrical engineer. This kind of interference is difficult to detect during construction but will cause problems to the users of the building. These clarification issues usually are found before the meetings but are brought to discussion during the meetings.

The V-IWS provides an opportunity to bring these issues to attention as soon as they are detected. Online message board as shown in figure 6.2 allows team members to leave a message to anyone in the team. Even though this is considered not real-time compared to other communication channel such as telephone, it is less delayed compared to on-site meetings. Furthermore, while telephone is more real-time, it requires both parties to be available at the same time which is normally during the office hours. The online message board allows team member to leave a message at any time. With today
technologies, the system can be more real-time if desired by adding functions like instant messaging or email alert.

In face-to-face communication, the attendees have the same access to shared documents or objects available in the meeting room. Most of these documents can be converted into digital form by using software such as Adobe Acrobat. Any document in digital form can be easily shared by V-IWS. Therefore, the need for onsite meeting is limited to visual inspection of the jobsite especially architectural work. With the advance of digital photography, the need of onsite inspection can be reduced. Even though it is
arguable that the system like V-IWS can replace face-to-face onsite meetings due to its lack of social interactions. It is clear that the computer mediated communication that support photo-image visualization like V-IWS can provide an alternative to onsite meetings especially when each team member locates far apart from each other.

### 6.2 Effects of the V-IWS on Material Delivery Process

According to Stukhart (1995), around 80% of the project schedule is control by material from the initial material acquisition to the delivery of the last item. A research done by Construction Industry Institute concluded that implementing of basic material management system resulted in 6% improvement in craft labor productivity and additional of 4-6% can be expected when a sophisticated computer control was implement (CII Publication 7-1, 1986). Inefficient management of construction material is considered a major cause of project delays and non value-added activities such as over transportation. In this section, a material delivery process at the jobsite which is an important part of the overall material management system is investigated. Non value-added activities cause by delay of delivery and potential used of V-IWS to improve process planning and control are identified.
6.2.1 Background of the Greenhouse Activities at USTL project

Part of the USTL project consists of 40,500 gsf. of instructional laboratories, classrooms and greenhouses for horticultural sciences. There are three greenhouses in this project. Van Wingerden Greenhouse Company, which is one of the leaders in this industry, is the subcontractor. The company manufactures 40 or more acres of greenhouse structures each year. The company’s home office is in Horse Shoe south of Asheville around 260 miles from the USTL site. The company has 27 full time employees at the manufacturing facility and approximately 30 construction workers under contract.

Most of the structure and engineering equipment used in the greenhouses are imported from Holland. The construction crew that has experience in building the greenhouses has moved back to Holland. The present crew has never built this type of greenhouses before. The company delegate who is member of the CFSC team comes to the site once a month to attend monthly meetings and check work progress. The floor of the greenhouses is not included in the subcontractor’s contract and will be done by the general contractor. This subcontractor’s delegate will coordinate with the general contractor and schedule the material delivery when the site is ready. The materials, then, will be shipped from the company’s yard located in Boone, North Carolina to the jobsite.
6.2.2 Data Collection

The materials of the first greenhouse were shipped in a single truck-load on Monday June 2\textsuperscript{nd}, 2003. The network camera on the roof of Garner Addition building was set to take and update a picture to the system every one minute. The process was observed and additional pictures also taken by using a digital camera. Figure 6.3 shows a
sample picture from the network camera. The overlay shows how the different materials are staged. The person that in charged of the delivery and unload had never seen the site before. The unloading and staging processes were planned at the moment based on current site condition. Small area shown on the right hand side of the figure was left clear as a working space.

6.2.3 Process Analysis

The total of 358 pictures was used to create a video clip used in process analysis. The truck arrived at the jobsite at 8:08 a.m. along with 6 crew members. The truck driver, then, needed to go to the site office which was at the other side of the site to get instructions from the general contractor about where to park the truck. After met with the general contractor, the driver learned that the truck could not enter the site at the moment because the site was not ready. The dirt needed to be removed from the area between the entrance and the greenhouse before the truck could unload the materials. The moving dirt process finished at 9:21 a.m. However, the truck still could not get into the site because 2 passenger cars that belong to another subcontractor obstructed the entrance. Since the truck arrived, the truck had been waiting for about 2 hours before moving into the site and unloaded the materials. The actual time for unloading was less than 2 hours.
From the time-line shown in figure 6.4, the time between 8:08 a.m. when the truck arrives to 10:05 a.m. when the truck starts moving into the jobsite are considered wasteful. If the truck were able to get into the site as soon as it arrived, the driver and 6 crew members would save more than half of the time they spent on the process. In addition, waste of time waiting because other resources are not ready for the process to start can cause tremendous collateral waste. In this particular case, when the truck arrived and could not enter the site, it blocked the survey crew that was working in that area (figure 6.5 a). The survey and other process that follow were also caused to delay by
the delivery of greenhouse materials. Figure 6.5 (b) shows the traffic problems caused by the truck waiting to enter the site. Many complaints were received on that morning. The delay on that morning during rush-hours appeared to affect both students and professors who were already late for classes.

(a) Interference with other processes  
(b) Hazardous traffic condition

Figure 6.5 Collateral waste caused by the truck waiting outside

6.2.4 Effects of V-IWS on Process Improvement

Implementing of V-IWS on the jobsite provides a tool to analyze what is happening in a particular process. However, the real benefit of the system is to allow CFSC team to improve process planning before the delivery date. There are hundreds of materials in and out from the jobsite during construction phase. The general contractor, as the one who takes full responsibility on the site, will have to coordinate with the subcontractors and suppliers on delivery schedule and staging area. The V-IWS provides
a tool that helps the general contractor controls all materials delivered to the jobsite. Online material delivery planning as shown in figure 6.6 allows subcontractors and suppliers to add, delete, or update delivery plan through the Internet. All information about what and when the materials will arrive as well as their staging area are recorded into project’s database.

With the V-IWS system, the general contractor does not have to rely only on telephone to coordinate the processes. He can login to system and review all materials that will be delivered today or any day in advance; as a result, he is allowed to manage space on the jobsite more efficiently. The suppliers can use real-time site photo images to analyze site condition and planning for the staging area. This is particularly helpful when the suppliers never visit the site before. A research has shown that better delivered process planning greatly increases productivity (Salim, 1993). The suppliers can use site picture, like the one shown in figure 6.3, to better plan staging of different structural members close to where they needed, hence reduces non value-added activities such as over transportation. In addition, the suppliers can also use real-time site photo to check last minute site condition before they depart in case of unforeseen events such as weather so any non value-added activities and consequent waste as shown in figure 6.5 (a) and (b) can be avoided.
In the context of supply chain management, implementing of V-IWS brings the general contractor, suppliers, and all CFSC team members closer together. Major engineering equipment such as elevator that needs to be fabricated in the factory at remote location now can be controlled more closely and synchronized with project’s master schedule. The ability to add network cameras as many as needed based on TCP/IP technology allows CFSC team to have real-time visual access to almost anywhere in the world that has access to the Internet. Photo-image visualization provides an alternative way to technical drawing and lengthy explanation for non technical
participants such as the owner or facility’s users. Browser based interface allows any project participants familiar with the Internet to use the system with little or no training.

6.3 Effect of the V-IWS on CFSC team’s satisfactions

This section describes the effect of the V-IWS on the CFSC team’s satisfactions after the system has been implemented at the USTL project. The team members involved in this analysis includes the owner, the facility’s user, the designers (architects and engineers), the general contractor, and the greenhouse subcontractor. The analysis is based on their opinions about how important they think the system is and what are the potential benefits that the system provides.

6.3.1 Data Collection

Ten team members who are using the V-IWS system were asked to fill out the system value evaluation questionnaire shown in appendix F. Eight members responded. The respondents include: 1 owner’s representative (NCSU), 1 professor who will be the user of the greenhouse, 2 general contractor’s engineers, 3 designers (architect and engineers), and 1 greenhouse subcontractor. The questionnaire consists of two parts. The first part is about respondents’ role in the project and general question such as how often they visit the site, the type of Internet connection they have, and how often they use
the system. The second part is the system’s feature rating and potential benefits based on 12 system’s features. The results of the questionnaire are presented in the next section.

6.3.2 General Characteristics of the Respondents

Except for 2 general contractors, all other respondents do not work full-time on the project. The owner’s representative visits the site everyday. The architect, who is also construction administrator, comes to the site 2 to 3 times a week. The user and other designers usually visit the site once a week. The greenhouse subcontractor, whose home office is located about 260 miles from the site, comes once a month for monthly meeting. Most of the respondents have been working on more than one project simultaneously. The designers, for example, have around 6 to 8 projects on hand at the same time while the subcontractor is currently working on 12 projects. All respondents have high-speed Internet connection available at either office or home. Most of the respondents except the general contractors use the V-IWS system almost everyday to monitor work progress. The general contractors use the system less often because they are working full-time onsite, thus monitoring work progress feature is less important for them.

6.3.3 System Value Rating

Part B of the questionnaire asks the respondents to rate the important level for each system feature. The rating range from 1 to 5 as 5 represents most important and 1
represents little or not important. The features being rated include still image, video, picture from outside the building, picture from inside the building, mobile camera, and etc. The result and the list of all 12 features are shown in figure 6.7.

![Figure 6.7 Value rating based on system’s features](image)

F1 = Real-time still image: Outside building  
F2 = Real-time site video image: Outside building  
F3 = Real-time still image: Inside building  
F4 = Real-time video image: Inside building  
F5 = Real-time still or video image from mobile camera  
F6 = Create time-lapse movie clip  
F7 = Create historical image archive & Visual As-built  
F8 = Automatic monitoring of site condition  
F9 = Real-time equipment status  
F10 = Notification of change, RFI, drawing & specification  
F11 = Material delivery schedule & procedure  
F12 = Automatic generation of daily report
From figure 6.7, the most important features ranked by the respondents are real-time site video image taken from outside building and real-time still or video image from mobile camera. The potential benefits from these features include increasing productivity, quality control, security, and problem solving. The less important feature is monitoring real-time equipment status. The result also reveals one interesting issue. All of the top 5 highest rating are features that utilize either real-time photo or video technology. This is consistent with the results from many researches that most people prefer communication channel that support visualization. The ability to keep pictures as historical record and visual as-built has very high rating from the owner and the user of the building. One comment from the user is that having photo-image as-built is very useful especially for non-technical person who is not familiar with 2-D construction drawing and all technical term.

Figure 6.8 shows value rating based on role of respondents. The owner gives the highest score for the overall system. In this case, the owner is working on 3 projects at the same time. Having access to real-time site images help save time by allow him to check work progress without leaving office. The result from the questionnaire also shows that different role has different expectation on the system. The subcontractor, for instance, uses the system everyday but just only to check the work progress of the greenhouse. Therefore, she gave highest value score for the real-time still image looking outside but lowest score for inside image. The general contractors, on the other hand, feel that using the system to check work progress is not a very important feature because
they are working full-time onsite; therefore, there is no need to use the system to check for the work progress except during weekend. However, they feel that some features such as real-time video and time-lapse video are very useful because they can use them to increase productivity and site security.

Figure 6.8 Comparison of overall value rating

6.4 Costs-Benefit Analysis of the V-IWS

This section presents the costs and benefits of the V-IWS system. As mentioned earlier that the system is extremely flexible and expandable, finding the exact costs of the system is not easy. Once the core system has been set up, hundreds of network devices
such as network camera, humidity and temperature detector can be added into the system as needed depending on the size of the project. Estimating the benefits of the system in term of dollar is even more difficult. In order to put cost benefit comparisons in to perspective, the costs of the system are based on the system implemented in this research.

6.4.1 System Costs

The costs of the V-IWS system implemented at USTL project can be broken down into 3 parts as follow:

1). Hardware: The hardware used in this system consists of 1 computer, 1 router, 2 repeaters (access points that support repeater mode), 2 high-gains antennas, and 3 network cameras. The costs of hardware are as follow (the cost of laptop computer used for measuring wireless signal is not included):

<table>
<thead>
<tr>
<th></th>
<th>Unit</th>
<th>Cost / Unit</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Server Computer (Used)</td>
<td>1</td>
<td>$250</td>
<td>$250</td>
</tr>
<tr>
<td>Router</td>
<td>1</td>
<td>$129</td>
<td>$129</td>
</tr>
<tr>
<td>High-gains Antenna</td>
<td>2</td>
<td>$210</td>
<td>$420</td>
</tr>
<tr>
<td>Repeater</td>
<td>2</td>
<td>$90</td>
<td>$180</td>
</tr>
<tr>
<td>Network Camera (StarDot’s NetCam)</td>
<td>1</td>
<td>$842</td>
<td>$842</td>
</tr>
<tr>
<td>Network Camera (Panasonic KX-HCM270)</td>
<td>1</td>
<td>$587</td>
<td>$587</td>
</tr>
<tr>
<td>Network Camera (D-Link DCS-1000W)</td>
<td>1</td>
<td>$449</td>
<td>$449</td>
</tr>
</tbody>
</table>

$2,857
2). **Software**: The software used to develop the system is Microsoft Office 2002 Professional. The Operating System is Microsoft Windows 2000 Professional. This software is widely used in most offices.

3). **ISP Fee**: The ISP fees for broadband Internet connection vary from $110 to $250 per month (for business with fixed IP address). In this research, the system is connected to the Internet through the University’s network.

The costs shown above are of the prototype system used for research purpose. The costs do not include the researcher’s time and efforts to develop and maintain the system. If the system were about to be used for business the cost of design and development will need to be considered.

### 6.4.2 System Benefits

Due to the flexibility of the system, its applications are limitless. This section describes only the benefits of the prototype system with 3 network cameras. The benefits in term of cost-savings can be described as direct and indirect cost-savings.

1). **Direct Cost-savings**: Direct cost-savings achieved by implementing the system is due to reducing the need for “unnecessary site visit” and “too much meetings.” Tremendous time and costs related to traveling can be saved
especially for remote team members whose offices are in different state or different country. The latest model of network cameras also transmit sound and allow the team members to control (pan, tilt, and zoom) the cameras from their office. Team members can even monitor humidity, temperature, and detect water by adding a few network devices into the system.

2). Indirect Cost-savings: In addition to travel-related savings, there are several indirect cost-savings from the system. It is extremely difficult to prove these cost-savings in terms of dollar. However strong evidence suggests that, in construction industry, these benefits are far more than direct cost-savings mentioned earlier. These indirect cost savings include:

- Improve information flow in construction project. Construction project managers typically spend 70% of their time dealing with data. Their activities include generating, managing, sending, collecting and analysis of data (Fisher and Yin, 1992). The V-IWS system helps reducing this work-load by providing project information center where the managers can get the information they needed quickly. The system can also reduce the manager’s time spent on paper work such as daily report and minutes of meeting. In large organizations, improving information flow can result in millions of dollar in saving. For instance, in a study done by BP Exploration (BPX), the $13 billion division of British Petroleum Company that explores for and produces
oil and gas, reducing of the time needed to locate and acquire information would increase efficiency and result in average annual saving of $10 to $20 million (Cross, 1997).

• Able to solve problems on-site immediately by using a mobile network camera. Having Wi-Fi network cover the entire jobsite allows wireless network camera to deliver real-time image of any location, inside or outside buildings, through the Internet. Engineers or experts from around the world can use the system solve the workface problem before it causes more damage.

• Create virtual workplace for remote CFSC members to allow the continuous of visual inspection. The architect, the owner or the users can avoid work delays due to rework cause by confusing information. This can also increase productivity, improve quality, and reduce cost.

• Increase safety and site security. The wireless network cameras allow workers to work at a safe distance and avoid hazardous environment. The camera can be attached to a robotic arm to provide visual of places like confined space or treatment tank which otherwise will need to send workers in. The system also increases site security when used as surveillance system.

• Increase participation in the decision-making process. The V-IWS allows a remote team member to participate in a process which is otherwise may not be able to due to travel restrictions.
• Enhancing supply chain integration. The system can be used to synchronize process undertaken at different locations. For example, construction manager in the US can monitor the elevators assembly in the factory in Japan so he can make sure that the elevator core will be ready when the elevator shipped to the site.

• The system can be used as a training tool. Photos and video clips created by the system can be made available to the Internet and used in training and education.

• Picture archives kept in the system can be used as historical record and visual as-built. Visual as-built provides the owner and non-technical facility’s users with real photos of what is behind the wall or underground such as utility line, waterproof membrane, insulations, and etc. Historical photo record can be used as evident in disputations.

• The system can be used as a marketing tool to attract more clients.

6.4.3 Cost Benefit Comparisons

As mention earlier that it is extremely hard to quantify indirect cost-savings in terms of dollar, however direct cost-savings alone is proved to outweigh the costs. Consider the following hypothetical project data and assumptions:
In 12 month period, assume weekly meetings can be reduced to monthly meetings and monthly meeting is reduced to quarterly. Therefore, 40 weekly meetings and 8 monthly meetings can be reduced in one year.

Assume there are 5 people in weekly meeting and 20 people in monthly meetings.

Average time spent in the meetings included traveling time assume to be 3 hours for the weekly and 4 hours for the monthly meetings.

Average cost per man-hour of the attendees is assumed to be $50 ($100,000 / year) including overhead and average traveling cost per trip is $40.

Fixed cost-savings per meeting due to reduced paperwork and time to prepare meeting minutes and meeting agenda assume to be $80.

Assume the V-IWS requires 52 hours per year for maintenance at the cost of $50 per hour.

Assume each team member spends average 5 minutes per working day on the system based on 250 working days per year.

The costs and benefits for this hypothetical project for 12 month period can be compared as follows:

<table>
<thead>
<tr>
<th>Costs</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardware</td>
<td>$2,857</td>
</tr>
<tr>
<td>ISP Fees $250 x 12</td>
<td>$3,000</td>
</tr>
<tr>
<td>Maintenance 52 x $50</td>
<td>$2,600</td>
</tr>
</tbody>
</table>
Time spent on the system =

25 x (250x5/60) x $50 = $26,042

Total Costs $34,499

Benefits: Weekly Meeting Savings =

40 x ((5x ((3x $50) + $40)) + $80) = $41,200

Monthly Meeting Savings =

8 x ((20x ((4x $50) + $40)) + $80) = $39,040

Total Benefits $80,240

Figure 6.9 shows cost-benefit comparisons at different percent reduction of meetings. At around 30% meeting reduction, the saving breaks even with the cost. If the
assumptions in this scenario are representative, then it can be concluded that when direct cost-savings from reducing onsite meetings alone is considered, the benefit of the V-IWS already exceeds the costs of the system.
7. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

7.1 Summary

Reports show that the performance of the construction industry has fallen behind manufacturing and managerial concepts that have proven useful in manufacturing are barely used in construction. The differences that hinder the copying of manufacturing tools include: 1) the fragmentation of the industry 2) uniqueness of construction project 3) temporary relationships between project participants 4) lowest bid approach (zero-sum game) and 5) lack of appropriated communication technologies that can be implemented on jobsite environment.

Research results point out that the major cause of low performance arises from the lack of effective communication among parties involved in a construction project. Project participants such as owners, designers, contractors, subcontractors, and suppliers belong to different organizations with different goals and business cultures. They form a temporary relationship referred to as Cross-Functional Supply Chain (CFSC) team. Each member of the team performs a unique service and, at the same time, coordinates with others to ensure a smooth flow of work. Traditionally, CFSC teams rely on open communication channels such as phone/radio, email, letter and face-to-face meeting to
distribute/share information. However, none of the channels is sufficient to cover all their needs. The omnipresent phone/radio, while fast and convenient, is limited to one-to-one communication. The face-to-face meetings, on the other hand, provide an opportunity to communicate any kind of information to every party at the same time (one-to-many) but asynchronous and expensive especially when the team includes members come from different city or even countries.

The communication channels are components of information logistics (IL). The goal of IL is to delivery the right information to the right person at the right time. The information is not limit to messages communicated between the CFSC team but also includes visual image, measurable site condition, equipment status, etc. Lack of a comprehensive IL system results in production waste and non value-added activities. In fact, the key hypothesis of this research project is that a state-of-the-art IL system will not only reduce production waste but also add more value to all participants. In order to study the concept of IL in the construction, four specific research objectives were defined: 1) Study and evaluate key communication channels used today in construction as well as state-of-the-art technologies, 2) Analyze the information flow between the main team members, 3) Develop and test a prototype IWS system and 4) Assess the effectiveness of the prototype.

The facility that was built for this research consists of an Integrated Wireless Site (IWS) network with state-of-the-art wireless technologies and web-based database
management system. Many managerial planning and control activities such as giving instruction to the workforce, problem solving, inspection, etc. are visual in nature. Based on this fact, the prototype IWS was designed so that the capture and sharing of visual information can be done in real-time from any location via the Internet. The system was implemented and tested on the Undergraduate Science Teaching Lab (USTL) project located on NC State main campus for 7 months. Weekly meeting minutes conducted by the general contractor and monthly meeting minutes conducted by the architect were collected and analyzed to find flow patterns of information shared between key project team members. Its effectiveness in reducing production waste was also analyzed. Finally, the system’s value was evaluated based on questionnaire surveys and personal interviews with the CFSC members who used the system.

7.2 Conclusions

The selected project for the field experiments, a four-story classroom and laboratory building, is representative of a mid-size project with intensive involvement of the end users. Special components of this project are three greenhouses built by a subcontractor from Horse Shoe south of Asheville around 260 miles from Raleigh. The project provided a unique opportunity to test and evaluate the key features of web-based concepts and allowed to address all four objectives. Following are the conclusions and findings organized according to those research objectives.
The First Objective: Study and evaluate key communication channels used today in construction as well as state-of-the-art technologies to underpin a synchronous information logistics model.

Key findings: 1) The project team relied on two communication channels: phone/radio and on-site meetings. Phone/radio was used when quick responses were needed. However, this channel is still limited to voice only and the members have to buy services from proprietary providers. When a complex issue was needed to be discussed and/or site visualization was required, the participants relied on on-site meetings. In this particular project, the CFSC team had both monthly and weekly on-site meetings. The monthly meeting usually lasted from 1 to 3 hours and comprised of approximately 20 attendees while the weekly meeting had an average of 5 attendees and lasted from 1 to 1 ½ hrs.

2) The observations highlighted problems related to spatial separations between architect, engineer, general contractor, and a subcontractor. For example, the greenhouse structural elements were prefabricated at the subcontractor’s yard 260 miles from Raleigh and shipped to the USTL site for erection. However, the general contractor was responsible for the foundation of the greenhouses which needed to be very precise. The processes of building the foundation and prefabrication were done in parallel. During the months preceding the
first delivery, the subcontractor had no direct access to the jobsite and relied on phone calls with the general contractor to confirm progress.

3) The material delivery truck that came to the site did not know where to park since it could not get into the site. This forced the truck to park on the public road creating serious hazardous safety for the site in tight and hectic location like USTL.

4) The successful installation of a V-IWS demonstrated that Internet and Wi-Fi technologies met the requirements of a functional construction IL system. The technologies are scalable, interactive, real-time, and affordable. According to the survey, all members in the CFSC team had internet connections both at home and at the office. Server-side technology such as Active Server Page (ASP) used to create interactive webpage ensures compatibility and user friendly for all team members.

5) Development in Wi-Fi standards and technology is continuing to increase the speed of wireless communication. During the past two years, the data rate of Wi-Fi network has increased from 11 Mbps (802.11b standard) to 54 Mbps (802.11g standard). At the same time, the cost of equipment dropped significantly. For instance, the prices of the wireless routers and repeaters used for this research dropped for more than 40% within 16 months.
The Second Objective: Analyze the information flow between the main team members of a mid-size building construction project.

As mentioned in the body of this thesis, many studies showed that meetings consumed most of the managers’ time and cause a lot of stress. Based on this fact, the analysis focused on the meeting held on-site, both weekly (WM) and monthly (MM).

Key findings: 1) In both WM and MM, the participants perform four functions as follow: a) inform, b) question, c) answer, and d) receive information. WM was conducted by the general contractor. The 6 subcontractors were required to either respond to the general contractor’s question or raise issues specifically relate to their work. MM, on the other hand, was conducted by the architect as the construction administrator. The architect, the owner, and the general contractor were all play major roles during each meeting.

2) Data from the analysis of 303 messages included in 36 WM showed that 89% of the messages shared among CFSC team were classified as inform/comment. 7% of the messages were question/request and 4% were classified as answer/respond.

3) Compared to WM, the analysis of 222 messages from 5 MM showed that 63% were inform/comment, 19% were question/request and 18% were answer/respond.
4) As expected, the largest percentage of the messages in MM (21%) related to clarification mainly caused by conflicts between drawings and specifications (architect, structure, and HVAC), CAD and functionality interference. It is important to note that many of these conflicts were detected much earlier but not discussed until the next meeting.

5) During WM, only 2.31% of the messages were related to clarification while 25%, the largest percentage of the messages, were related to look-ahead plan.

**The Third Objective:** Develop and test a prototype web-based communication system to support real-time and interactive information sharing among all project participants, both technical and non-technical.

**Key findings:**

1) Field data proved that it was possible to implement a long-haul Wi-Fi network with multiple wireless devices such as access points and network cameras on an active construction site.

2) Wireless cameras performed well within the construction site environment. However, the performance of the network was impacted by the interference from equipments, such as microwave, generator, and blower, located near the repeaters. As a result, the real-time video might not work while the still image function was working.
3) Type of building materials and the thickness effect the attenuation (a reduction of signal strength during transmission). Concrete walls cause high attenuation than drywalls or glass walls. To overcome such effects, additional repeaters can be used strategically.

4) Wireless systems were prone to experience interference by other wireless networks as was the case in this research. The longer the wireless ranges, the higher the interference. In this particular case, there was interference from up to 5 different wireless networks on the V-IWS that had coverage radius approximately 1,700 feet from Mann Hall Building. Most of these networks were implemented by NC State University.

5) The experiences gained from installed and tested wireless network in construction site underlined the importance of planning. The location of the repeaters and/or access points including all network devices must be flexible since they need to be relocated as the building grows. In addition, an appropriated procedure according to rules and regulations such as limit power of antenna and setup network name (SSID) need to be strictly followed so that it does not interfere with other wireless networks. Advance planning and pre-test are strongly recommended.
The Fourth Objective: Assess the effectiveness of the prototype web-based information system in reducing production waste and adding value for different project participants including the users of the building.

Conclusions related to this objective are critical since they provide the basis to justify the implementation of V-IWS. Because of the industry’s aversion to change, it was encouraged to observe that most CFSC members used the system.

Key findings: 1) The survey showed that all CFSC members except the general contractor used the V-IWS everyday or almost everyday to monitor the jobsite. Since the general contractor worked full time on-site there was less need to use the system (1 to 3 times per month).

2) According to the questionnaire, the owner representative gave highest overall value to the system (4.2 out of 5.0) because it allowed him to monitor the jobsite from his office.

3) When compared based on V-IWS features, the top 5 features with highest value score were (based on scale from 1 to 5):
   
a) Real-time video to monitor outside building (4.0).

b) Real-time still or video image from mobile camera (4.0).

c) Real-time still image to monitor outside building (3.9)

d) Time-lapse movie clip (3.7)

e) Historical image archive & visual as-built (3.6)
It is interesting to note that all top 5 features are related to visualization, thus, confirming the recognized value of visual-based IL system.

4) The costs-benefits analysis for the USTL project showed that savings from reducing the number of meetings by 30% would break even the costs of the system.

5) Interviews with individual CFSC member confirmed that the V-IWS effectively reduces the number of unnecessary site visits. Before the system was implemented, the owner representative had to go to the jobsite everyday just to see what was going on. After the system had been implemented, the jobsite could be watched from his office which helped reduce the needs to go to the jobsite.

6) The V-IWS offers many opportunities to reduce non value-added processes in material management. The data analysis of the greenhouse structure delivery process showed that the V-IWS could reduce waiting time of the delivery truck by half. Reducing loading or unloading cycle time also reduce the chance to obstruct other processes and increase safety.

7) The greenhouse subcontractor used the system to daily monitor the erection progress from the home office in Ashville. This was crucial because the crew had no experience in building this type of greenhouses. The interviewed foreman indicated that having video records of a previous installation would ease his work. This incident
reveals the ability of V-IWS to be used as both a monitoring and training tool for inexperienced crew.

8) Based on the interview with the professor who will be the user of the greenhouses, the time-lapse videos and “visual as-built” automatically created by the system add more value to the system more than it has been originally expected. Unlike CAD drawing, the real photos of greenhouse during construction are far more useful for her who is not familiar with technical terms and symbols used in construction drawing. In addition, the time-lapse video showed the greenhouse erection process will be used as teaching material in the classroom.

This research proved that the IL system enabled by state-of-the-art technologies is feasible in typical mid-size construction projects. Such a system allows all participants to work closely together in order to save time, money as well as increasing project performance. However, these benefits can be achieved only when all participants are willing to share information with each other. Therefore, trust among team members is imperative and must be established for the system to be used successfully.

7.3 Recommendation for Future Research

The following section outlines potential future research arising from this research.
• **Understanding of Technology Adoption Process:**

Implementation of any new technology requires changes on the way people work. Even though, V-IWS has been proved to be useful, not all team members are willing to change the way they work at the first place. Adoption process is usually take time. The behavior and factors that affect adoption process such as sharing of the gain value are important and need to be studied.

• **The Effects of Push and Pull Information Logistics System on Decision Making Process:**

The information flowed in an IL system can be either push or pull. For instance, data query from a database is considered “pull” while message or email alert is “push.” Study of push and pull effects is imperative especially for decision making process and risk management.

• **The Effects of Remote Management on Performance:**

The IWS approach provide an opportunity for the management to planning, monitoring, and control jobsite 24/7 through various network devices such as network cameras, equipments’ black box, and etc. This certainly changes the way people, at every level, work. The long term effects of this change on workforce’s performance are needed to be studied.
LIST OF REFERENCES


Appendix A

FCC Regulation on Wireless Communication

(Title 47 Part 15 Section 15.205, 15.209, 15.247)
Sec. 15.205 Restricted bands of operation.

(a) Except as shown in paragraph (d) of this section, only spurious emissions are permitted in any of the frequency bands listed below:

<table>
<thead>
<tr>
<th>MHz</th>
<th>MHz</th>
<th>MHz</th>
<th>GHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.090-0.110</td>
<td>16.42-16.423</td>
<td>399.9-410</td>
<td>4.5-5.15</td>
</tr>
<tr>
<td>0.495-0.505</td>
<td>16.69475-16.69525</td>
<td>608-614</td>
<td>5.35-5.46</td>
</tr>
<tr>
<td>4.125-4.128</td>
<td>25.5-25.67</td>
<td>1300-1427</td>
<td>8.025-8.5</td>
</tr>
<tr>
<td>4.17725-4.17775</td>
<td>37.5-38.25</td>
<td>1435-1626.5</td>
<td>9.0-9.2</td>
</tr>
<tr>
<td>4.20725-4.20775</td>
<td>73-74.6</td>
<td>1645.5-1646.5</td>
<td>9.3-9.5</td>
</tr>
<tr>
<td>6.215-6.218</td>
<td>74.8-75.2</td>
<td>1660-1710</td>
<td>10.6-12.7</td>
</tr>
<tr>
<td>6.26775-6.26825</td>
<td>108-121.94</td>
<td>1718.8-1722.2</td>
<td>13.25-13.4</td>
</tr>
<tr>
<td>8.291-8.294</td>
<td>149.9-150.05</td>
<td>2310-2390</td>
<td>15.35-16.2</td>
</tr>
<tr>
<td>8.362-8.366</td>
<td>156.52475-156.52525</td>
<td>2483.5-2500</td>
<td>17.7-21.4</td>
</tr>
<tr>
<td>8.37625-8.38675</td>
<td>156.7-156.9</td>
<td>2655-2900</td>
<td>22.01-23.12</td>
</tr>
<tr>
<td>8.41425-8.41475</td>
<td>162.0125-167.17</td>
<td>3260-3267</td>
<td>23.6-24.0</td>
</tr>
<tr>
<td>12.29-12.293</td>
<td>167.72-173.2</td>
<td>3332-3339</td>
<td>31.2-31.8</td>
</tr>
<tr>
<td>12.51975-12.52025</td>
<td>240-285</td>
<td>3345.8-3358</td>
<td>36.43-36.5</td>
</tr>
<tr>
<td>12.57675-12.57725</td>
<td>322-335.4</td>
<td>3600-4400</td>
<td></td>
</tr>
</tbody>
</table>

(b) Except as provided in paragraphs (d) and (e) of this section, the field strength of emissions appearing within these frequency bands shall not exceed the limits shown in Sec. 15.209. At frequencies equal to or less than 1000 MHz, compliance with the limits in Sec. 15.209 shall be demonstrated using measurement instrumentation employing a

\[1\] Until February 1, 1999, this restricted band shall be 0.490-0.510 MHz.

\[2\] Above 38.6
CISPR quasi-peak detector. Above 1000 MHz, compliance with the emission limits in Sec. 15.209 shall be demonstrated based on the average value of the measured emissions. The provisions in Sec. 15.35 apply to these measurements.

(c) Except as provided in paragraphs (d) and (e) of this section, regardless of the field strength limits specified elsewhere in this subpart, the provisions of this section apply to emissions from any intentional radiator.

(d) The following devices are exempt from the requirements of this section:

1. Swept frequency field disturbance sensors operating between 1.705 and 37 MHz provided their emissions only sweep through the bands listed in paragraph (a) of this section, the sweep is never stopped with the fundamental emission within the bands listed in paragraph (a) of this section, and the fundamental emission is outside of the bands listed in paragraph (a) of this section more than 99% of the time the device is actively transmitting, without compensation for duty cycle.

2. Transmitters used to detect buried electronic markers at 101.4 kHz which are employed by telephone companies.

3. Cable locating equipment operated pursuant to Sec. 15.213.

4. Any equipment operated under the provisions of Sec. 15.253 or Sec. 15.255.

5. Biomedical telemetry devices operating under the provisions of Sec. 15.242 of this part are not subject to the restricted band 608-614 MHz but are subject to compliance within the other restricted bands.

6. Transmitters operating under the provisions of subparts D or F of this part.

(e) Harmonic emissions appearing in the restricted bands above 17.7 GHz from field disturbance sensors operating under the provisions of Sec. 15.245 shall not exceed the limits specified in Sec. 15.245(b).

<table>
<thead>
<tr>
<th>Frequency (MHz)</th>
<th>Field strength (microvolts/meter)</th>
<th>distance (meters)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.009-0.490</td>
<td>2400/F(kHz)</td>
<td>300</td>
</tr>
<tr>
<td>0.490-1.705</td>
<td>24000/F(kHz)</td>
<td>30</td>
</tr>
<tr>
<td>1.705-30.0</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>30-88</td>
<td>100 **</td>
<td>3</td>
</tr>
<tr>
<td>88-216</td>
<td>150 **</td>
<td>3</td>
</tr>
<tr>
<td>216-960</td>
<td>200 **</td>
<td>3</td>
</tr>
<tr>
<td>Above 960</td>
<td>500</td>
<td>3</td>
</tr>
</tbody>
</table>

** Except as provided in paragraph (g), fundamental emissions from intentional radiators operating under this section shall not be located in the frequency bands 54-72 MHz, 76-88 MHz, 174-216 MHz or 470-806 MHz. However, operation within these frequency bands is permitted under other sections of this part, e.g., Sec. Sec. 15.231 and 15.241.

(b) In the emission table above, the tighter limit applies at the band edges.

(c) The level of any unwanted emissions from an intentional radiator operating under these general provisions shall not exceed the level of the fundamental emission. For intentional radiators which operate under the provisions of other sections within this part and which are required to reduce their unwanted emissions to the limits specified in this table, the limits in this table are based on the frequency of the unwanted emission and not the fundamental frequency. However, the level of any unwanted emissions shall not exceed the level of the fundamental frequency.

(d) The emission limits shown in the above table are based on measurements employing a CISPR quasi-peak detector except for the frequency bands 9-90 kHz, 110-490 kHz and above 1000 MHz. Radiated emission limits in these three bands are based on measurements employing an average detector.

(e) The provisions in Sec. Sec. 15.31, 15.33, and 15.35 for measuring emissions at distances other than the distances specified in the above table, determining the frequency range over which radiated emissions are to be measured, and limiting peak emissions apply to all devices operated under this part.

(f) In accordance with Sec. 15.33(a), in some cases the emissions from an intentional radiator must be measured to beyond the tenth harmonic of the highest fundamental frequency designed to be emitted by the intentional radiator because of the incorporation of a digital device. If measurements above the tenth harmonic are so required, the radiated emissions above the tenth harmonic shall comply with the general radiated emission limits applicable to the incorporated digital device, as shown in Sec. 15.109 and as based on the frequency of the emission being measured, or, except for emissions contained in the restricted frequency bands shown in Sec. 15.205, the limit on spurious emissions.
emissions specified for the intentional radiator, whichever is the higher limit. Emissions which must be measured above the tenth harmonic of the highest fundamental frequency designed to be emitted by the intentional radiator and which fall within the restricted bands shall comply with the general radiated emission limits in Sec. 15.109 that are applicable to the incorporated digital device.

(g) Perimeter protection systems may operate in the 54-72 MHz and 76-88 MHz bands under the provisions of this section. The use of such perimeter protection systems is limited to industrial, business and commercial applications.

least 15 non-overlapping channels. The average time of occupancy on any channel shall not be greater than 0.4 seconds within a period of 0.4 seconds multiplied by the number of hopping channels employed. Frequency hopping systems which use fewer than 75 hopping frequencies may employ intelligent hopping techniques to avoid interference to other transmissions. Frequency hopping systems may avoid or suppress transmissions on a particular hopping frequency provided that a minimum of 15 non-overlapping channels are used.

(2) Systems using digital modulation techniques may operate in the 902-928 MHz, 2400-2483.5 MHz, and 5725-5850 MHz bands. The minimum 6 dB bandwidth shall be at least 500 kHz.

(b) The maximum peak output power of the intentional radiator shall not exceed the following:

(1) For frequency hopping systems in the 2400-2483.5 MHz band employing at least 75 hopping channels, and all frequency hopping systems in the 5725-5850 MHz band: 1 Watt. For all other frequency hopping systems in the 2400-2483.5 band: 0.125 Watt.

(2) For frequency hopping systems operating in the 902-928 MHz band: 1 watt for systems employing at least 50 hopping channels; and, 0.25 watts for systems employing less than 50 hopping channels, but at least 25 hopping channels, as permitted under paragraph (a)(1)(i) of this section.

(3) For systems using digital modulation in the 902-928 MHz, 2400-2483.5 MHz, and 5725-5850 MHz bands: 1 Watt.

(4) Except as shown in paragraphs (b)(3) (i), (ii) and (iii) of this section, if transmitting antennas of directional gain greater than 6 dBi are used the peak output power from the intentional radiator shall be reduced below the stated values in paragraphs (b)(1) or (b)(2) of this section, as appropriate, by the amount in dB that the directional gain of the antenna exceeds 6 dBi.

(i) Systems operating in the 2400-2483.5 MHz band that are used exclusively for fixed, point-to-point operations may employ transmitting antennas with directional gain greater than 6 dBi provided the maximum peak output power of the intentional radiator is reduced by 1 dB for every 3 dB that the directional gain of the antenna exceeds 6 dBi.

(ii) Systems operating in the 5725-5850 MHz band that are used exclusively for fixed, point-to-point operations may employ transmitting antennas with directional gain greater than 6 dBi without any corresponding reduction in transmitter peak output power.

(iii) Fixed, point-to-point operation, as used in paragraphs (b)(3)(i) and (b)(3)(ii) of this section, excludes the use of point-to-multipoint systems, omnidirectional applications, and multiple co-located intentional radiators transmitting the same information. The operator of the spread spectrum intentional radiator or, if the equipment is professionally installed, the installer is responsible for ensuring that the system is used exclusively for fixed, point-to-point operations. The instruction manual furnished with the intentional radiator shall contain language in the installation instructions informing the operator and the installer of this responsibility.

(5) Systems operating under the provisions of this section shall be operated in a manner that ensures that the public is not exposed to radio frequency energy levels in excess of the Commission's guidelines. See Sec. 1.1307(b)(1) of this chapter.
(c) In any 100 kHz bandwidth outside the frequency band in which the spread spectrum or digitally modulated intentional radiator is operating, the radio frequency power that is produced by the intentional radiator shall be at least 20 dB below that in the 100 kHz bandwidth within the band that contains the highest level of the desired power, based on either an RF conducted or a radiated measurement. Attenuation below the general limits specified in Sec. 15.209(a) is not required. In addition, radiated emissions which fall in the restricted bands, as defined in Sec. 15.205(a), must also comply with the radiated emission limits specified in Sec. 15.209(a) (see Sec. 15.205(c)).

(d) For digitally modulated systems, the peak power spectral density conducted from the intentional radiator to the antenna shall not be greater than 8 dBm in any 3 kHz band during any time interval of continuous transmission.

(e) [Reserved]

(f) For the purposes of this section, hybrid systems are those that employ a combination of both frequency hopping and digital modulation techniques. The frequency hopping operation of the hybrid system, with the direct sequence or digital modulation operation turned off, shall have an average time of occupancy on any frequency not to exceed 0.4 seconds within a time period in seconds equal to the number of hopping frequencies employed multiplied by 0.4. The digital modulation operation of the hybrid system, with the frequency hopping operation turned off, shall comply with the power density requirements of paragraph (d) of this section.

(g) Frequency hopping spread spectrum systems are not required to employ all available hopping channels during each transmission. However, the system, consisting of both the transmitter and the receiver, must be designed to comply with all of the regulations in this section should the transmitter be presented with a continuous data (or information) stream. In addition, a system employing short transmission bursts must comply with the definition of a frequency hopping system and must distribute its transmissions over the minimum number of hopping channels specified in this section.

(h) The incorporation of intelligence within a frequency hopping spread spectrum system that permits the system to recognize other users within the spectrum band so that it individually and independently chooses and adapts its hopsets to avoid hopping on occupied channels is permitted. The coordination of frequency hopping systems in any other manner for the express purpose of avoiding the simultaneous occupancy of individual hopping frequencies by multiple transmitters is not permitted.

Note: Spread spectrum systems are sharing these bands on a noninterference basis with systems supporting critical Government requirements that have been allocated the usage of these bands, secondary only to ISM equipment operated under the provisions of part 18 of this chapter. Many of these Government systems are airborne radiolocation systems that emit a high EIRP which can cause
interference to other users. Also, investigations of the effect of spread spectrum interference to U. S. Government operations in the 902-928 MHz band may require a future decrease in the power limits allowed for spread spectrum operation.

Appendix B

NCSU Policy on Wireless Communication
Communication Technologies and Information Technology Division
Rules for Implementation of Wireless Networks at NC State

Authority
Issued by the Vice Provost for Information Technology and Associate Vice Chancellor for Resource Management and Information Systems; approved by the University Information Technology Committee, December 13, 2002

Note: The use of data networking resources at NC State, including wireless, is governed by federal and state law, and University policies and procedures. NC State's Communication Technologies (ComTech), the University's data network and Internet service provider, is responsible for NC State's network infrastructure and all connections to it, including wireless. ComTech has the authority to block wireless transmitters and other wireless devices from access to the University's production data network, as well as request termination of the use of any other device that interferes with the security or operation of the official NC State wireless units, or the campus network, or that do not comply with standards approved by the University Information Technology Committee (see section II, below).

Related Policies
Board of Trustee Policy - Computer Use; Administrative Regulations - Computer Use

Contact Info
ComTech: 919-515-7099

I. Purpose

The following rules and guidelines for wireless access to the NC State data network have been implemented to preserve the security, utility and flexibility of the campus data network infrastructure and computing systems. Since a majority of the wireless network standards in use today use ISM (Instrumentation, Scientific, and Medical) bands of radio frequencies (900MHz, 2.4GHz, and 5GHz) that the Federal Communications Commission (FCC) does not regulate or restrict, the University must manage these frequency bands to provide a reliable production wireless network.

II. Scope

A. This document applies to the implementation of all wireless networking at NC State
B. For this document, wireless networks on the campus are divided into two categories:

1. NC State public wireless networks are those designed, built and maintained by ComTech for use by NC State faculty, staff, and students who have valid University computing accounts.

The ComTech wireless network implementation is part of a campus-wide Nomad Computing Environment. The Nomad Computing Environment uses Dynamic Host Configuration Protocol (DHCP) to provide ubiquitous and seamless mobile computing resources. The NC State wireless network infrastructure allows portable computing devices with wireless network interfaces to
connect to the NC State network uses IEEE 802.11b-compliant technology at the present time. This may change as other technology options mature.

2. NC State private wireless networks are those that are not funded, designed, built, and maintained by ComTech, but are installed and maintained by NC State colleges, departments, units, organizations or authorized individuals. The devices must be registered and the installation approved.

### III. Implementation of NC State public wireless networks

A. ComTech is responsible for obtaining the funding and for the design, purchase, installation, and management of the NC State public wireless network.

B. Priorities for installation will be determined by a cooperative effort between ComTech and the Infrastructure Subcommittee of the University Information Technology Committee. Once the priorities have been set, the subcommittee must approve any changes to the priorities. In cases where a campus organization needs to have public wireless networking installed ahead of schedule, ComTech will work with the organization to fulfill that need as quickly as possible, but the organization may be charged an installation fee (to be determined by ComTech) to offset additional costs not provided for in the ComTech budget.

C. Configuration standards for hardware clients on NC State public wireless network are as follows:

1. Service Set Identifier (SSID) = ncsu
2. Internet Protocol (IP) setting = Dynamic Host Control Protocol (DHCP)
3. Encryption = None

D. The NC State public wireless network may be used by NC State students, faculty, and staff who have a valid NC State computing account login ID, password and properly configured portable computer. Guests of the University may obtain a temporary login ID and password for logging into the system. In order to get a valid connection, all NC State public wireless network clients must use a web browser (Netscape Communicator, Internet Explorer, Mozilla, Opera, Lynx, etc.) to authenticate to the nomadic computing environment. The login page will appear when the user's web browser requests a web page. After successful authentication, the user will be able to use the campus network and the Internet.

E. Running remote services (web server, ftp server, nfs server, any person-to-person file sharing services, etc.) is PROHIBITED on the NC State Nomad Computing Environment and on public wireless networks. However, users of Nomad Computing Environment and public wireless networks will be able to connect to such services provided elsewhere.

F. All traffic to and from the Nomad computing environment is logged and associated with the user, as permitted by NC State Administrative Regulations, section II, G.

G. Users of the NC State public wireless network are requested to report any problems they encounter with the public wireless network or the Nomad computing environment immediately to the Network Operations Center (NOC) by phone (513-9675) or by e-mail to support@ncsu.edu. The user should have the following information available for the consultant:
1. Physical location of where the problem was encountered
2. Vendor of the wireless networking card being used
3. Wireless networking configuration
4. IP configuration obtained

H. Wireless network users are responsible for the security of the data transmissions they send over the wireless network. They should therefore be strongly encouraged to use secure application-level protocols (secure shell, secure web, VPN, etc.) when sensitive information traverses the wireless network; otherwise, they should move to the wired campus network.

IV. Implementation of private wireless networks on campus

A. Those who implement private wireless networks on campus are responsible for compliance with the rules, restrictions and provisions described in this document and for support of the private wireless network, including the network traffic.

B. Those who implement private wireless networks may employ wireless encryption technology if desired. They should be aware, however, that current wireless encryption technologies are weak, and it remains possible to eavesdrop and to passively decrypt wireless networking traffic.

C. Departments and authorized individuals may set up private wireless networks on campus as long as their installation does not interfere with the NC State public wireless network and the private wireless network is set up in compliance with the following standards:

1. Transmitter (access point or base station) registration
   All wireless networking transmitters MUST be registered in DNS with a descriptive name in the format of building-nearest room#-type-channel (e.g., "withers-410-proxim-6"). In most cases, registration will be done by the local LAN administrator.

2. Channel selection
   Wireless transmitters' channels must be configured so as not to disrupt any NC State public wireless networking transmitters or other private wireless networking transmitters. Contact ComTech for appropriate channel selection. Administrators of neighboring private wireless networks should also be consulted.

3. Access control
   All private wireless transmitters MUST be configured to allow only known client hardware to use the network. This is best done by setting the list of client Media Access Control (MAC) addresses that are allowed to use the private wireless network. Implementers of private wireless transmitters will be held responsible for the actions of those who access the campus network from those devices.

4. SSID (Service Set Identification)
   The SSID must not be set to "ncsu." SSID selection should be coordinated with administrators of neighboring private wireless networks.

5. Configuration password
   All transmitter configuration interfaces must be password protected with a non-default and hard-to-guess password. (See http://www.itsecurity.com/asktecs/jun301.htm, for examples.)
6. SNMP (Simple Network Management Protocol)
SNMP strings should not be the default and should have access lists assigned where possible.

7. Power settings
Private wireless transmitters should use the lowest possible power output that provides the needed coverage area.

8. FCC regulations
All private wireless transmitter configurations must be within FCC regulations for dissipated power, etc. (Available from http://www.access.gpo.gov/nara/cfr/waisidx_01/47cfr15_01.html. Section 15.247 covers the amount of radiated power in the 2.4Ghz band.)

9. Fire codes
All private wireless transmitters must be installed so they do not violate fire codes. Contact the NC State Senior Inspector of Fire Protection (515-2568) with questions.
Appendix C

Sample of ASP Code
<html>
<head>
<meta http-equiv="Content-Language" content="en-us"/>
<meta http-equiv="Content-Type" content="text/html; charset=windows-1252">
<meta name="GENERATOR" content="Microsoft FrontPage 4.0">
<meta name="ProgId" content="FrontPage.Editor.Document">
<title>Collaboration tools</title>
<style fprolloverstyle>A:hover {font-size: 14pt; font-weight: bold}</style>
</head>
<body bgcolor="#000080" link="#FFFF00" vlink="#00FFFF">
<%@ Language=VBScript %>

<% Response.Buffer = True %>

'Option Explicit
Dim Conn
Dim sqlUser
Dim RsUser
Dim strhttp
strhttp = Request.ServerVariables("HTTP_Refferer")

Set Conn = server.createobject("ADODB.Connection")
    Conn.open "wils_db", "", ""
    session("Connection") = Conn
On Error Resume Next

    If isempty(Request.Form("username")) or isempty(Request.Form("usrpwd"))
Then
Response.Redirect "\USTL/SM_logout.asp?login=1"

Else

'to see if Username & psw in database
sqlUser = "select * from LoginUser_power Where _
   & " UserName = " & Request.Form("username") & " and _
   & "Password = " & Request.Form("usrpwd") & ""
'Response.Write sqlUser
set RsUser = Conn.Execute(sqlUser)
If RsUser.BOF or RsUser.EOF Then
   Response.Redirect "\USTL/SM_logout.asp?login=1"
else
   session("UserName") = RsUser("UserName")
   session("PWS") = RsUser("Password")
End If

End If

Set RsUser=Nothing
If Conn.State = adStateOpen Then
Conn.Close
Set Conn = Nothing
End If

%

<p align="center"><font face="Arial" size="6" color="#FFFFFF"><b>Collaborative Tools</b></font></p>
<p>&nbsp;</p>
<table border="2" width="100%" height="411">
   <tr>
      <td width="34%" height="50" bgcolor="#0099CC">
         <p align="center"><font face="Arial" color="#FFFFFF"><b>Tools</b></font></p>
      </td>
      <td width="66%" height="50" bgcolor="#0099CC">
         <p align="center"><font face="Arial" color="#FFFFFF"><b>Tools</b></font></p>
      </td>
   </tr>
</table>
<table>
<thead>
<tr>
<th><img src="#" alt="Instruction / Description" /></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Panasonic CAM</strong>&lt;br&gt;<a href="http://suchart.ce.ncsu.edu:81/ViewerFrame?Mode=Motion">Live Video (for fast connection)</a> target=&quot;_blank&quot;</td>
</tr>
</tbody>
</table>
for archive, <a href="Dlink_archive.asp" target="_blank">Click Here</a>

D-link CAM instruction:

1. Click refresh toolbar to see most update still picture
2. To upload a series of still picture to the server (live video mode only) click on Image Upload &quot;on&quot; for 10 sec. to 1 min. and then click &quot;off&quot;. Do not upload more than 1 minute.

Humidity & Temperature

Online Material Delivery Plan

View, add, and remove material delivery plan

Online
<table>
<thead>
<tr>
<th>Message Board</th>
<th>Post and read message for all team members</th>
</tr>
</thead>
<tbody>
<tr>
<td>Get Direction</td>
<td>Link to MapQuest to get direction, map, and aerial photo</td>
</tr>
<tr>
<td>Get Weather Forecast</td>
<td>Link to AccuWeather to get hourly weather forecast</td>
</tr>
</tbody>
</table>

<p><font color="#FFFFFF" face="Arial"><a href="INDEX.HTM">USTL Home</a></font></p>
Appendix D

Sample of Signal Strength and Quality Data
## Wireless Site Survey

**Repeater:** RP-1  
**Location:** 3rd Floor  
**Date:** 3/4/2003  
**Time:** 2:30  
**Condition:** Fair

<table>
<thead>
<tr>
<th>Point</th>
<th>Grid Line / Location</th>
<th>Link Quality</th>
<th>Signal Strength</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Low</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>1</td>
<td>6-J</td>
<td>20</td>
<td>45</td>
<td>21</td>
</tr>
<tr>
<td>2</td>
<td>6-H</td>
<td>32</td>
<td>60</td>
<td>37</td>
</tr>
<tr>
<td>3</td>
<td>6-G</td>
<td>30</td>
<td>72</td>
<td>55</td>
</tr>
<tr>
<td>4</td>
<td>6-F</td>
<td>45</td>
<td>84</td>
<td>63</td>
</tr>
<tr>
<td>5</td>
<td>6-E</td>
<td>30</td>
<td>65</td>
<td>55</td>
</tr>
<tr>
<td>6</td>
<td>6-D</td>
<td>50</td>
<td>95</td>
<td>54</td>
</tr>
<tr>
<td>7</td>
<td>6-C</td>
<td>0</td>
<td>70</td>
<td>37</td>
</tr>
<tr>
<td>8</td>
<td>6-B</td>
<td>25</td>
<td>50</td>
<td>30</td>
</tr>
<tr>
<td>9</td>
<td>6-A</td>
<td>23</td>
<td>45</td>
<td>29</td>
</tr>
<tr>
<td>10</td>
<td>5-A</td>
<td>10</td>
<td>85</td>
<td>22</td>
</tr>
<tr>
<td>11</td>
<td>5-B</td>
<td>0</td>
<td>35</td>
<td>24</td>
</tr>
<tr>
<td>12</td>
<td>5-C</td>
<td>12</td>
<td>30</td>
<td>25</td>
</tr>
<tr>
<td>13</td>
<td>5-D</td>
<td>23</td>
<td>45</td>
<td>20</td>
</tr>
<tr>
<td>14</td>
<td>5-E</td>
<td>15</td>
<td>50</td>
<td>23</td>
</tr>
<tr>
<td>15</td>
<td>5-F</td>
<td>25</td>
<td>32</td>
<td>28</td>
</tr>
<tr>
<td>16</td>
<td>5-G</td>
<td>20</td>
<td>45</td>
<td>27</td>
</tr>
<tr>
<td>17</td>
<td>5-H</td>
<td>23</td>
<td>42</td>
<td>15</td>
</tr>
<tr>
<td>18</td>
<td>5-J</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>19</td>
<td>4-J</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>20</td>
<td>4-H</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>21</td>
<td>4-G</td>
<td>0</td>
<td>22</td>
<td>8</td>
</tr>
<tr>
<td>22</td>
<td>4-F</td>
<td>10</td>
<td>25</td>
<td>12</td>
</tr>
<tr>
<td>23</td>
<td>4-E</td>
<td>4</td>
<td>18</td>
<td>10</td>
</tr>
<tr>
<td>24</td>
<td>4-D</td>
<td>2</td>
<td>13</td>
<td>14</td>
</tr>
<tr>
<td>Point</td>
<td>Grid Line / Location</td>
<td>Link Quality</td>
<td>Signal Strength</td>
<td>Remark</td>
</tr>
<tr>
<td>-------</td>
<td>----------------------</td>
<td>--------------</td>
<td>-----------------</td>
<td>--------</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Low</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>25</td>
<td>4-C</td>
<td>10</td>
<td>22</td>
<td>8</td>
</tr>
<tr>
<td>26</td>
<td>4-B</td>
<td>8</td>
<td>45</td>
<td>6</td>
</tr>
<tr>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
</tr>
<tr>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
</tr>
<tr>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
</tr>
<tr>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
<td>.</td>
</tr>
<tr>
<td>52</td>
<td>1-H</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
<tr>
<td>a</td>
<td>Garner Addition' Roof</td>
<td>85</td>
<td>100</td>
<td>92</td>
</tr>
<tr>
<td>b</td>
<td>Garner Hall' Roof</td>
<td>0</td>
<td>85</td>
<td>0</td>
</tr>
</tbody>
</table>

**Signal from Router**

<table>
<thead>
<tr>
<th></th>
<th>Garner Addition' Roof</th>
<th>Low</th>
<th>High</th>
<th>0</th>
<th>22</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td></td>
<td>0</td>
<td>65</td>
<td>0</td>
<td>22</td>
</tr>
<tr>
<td>b</td>
<td>Garner Hall' Roof</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Appendix E

Information Flow Analysis Form
Meeting Date __________        Time Start _____End _____
Meeting Type: __________________________
Number of Attendees _______

<table>
<thead>
<tr>
<th>Role</th>
<th>Attendee Functions</th>
<th>Information Types</th>
<th>RIA</th>
<th>Lag Time (day)</th>
<th>Support Material / Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Inform / Comment</td>
<td>T1 T2 T3 T4 T5 T6</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Request / Question</td>
<td>T7 T8 T9 T10 T11</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Respond / Answer</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Receive</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Social</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

T1 = Progress Report  T2 = Look-ahead Plan  T3 = Warning / Upcoming Concern  T4 = Change of Condition  
T5 = Change of Requirement  T6 = Clarification  T7 = Confirmation  T8 = RFI  
T9 = Expedite / Reminder  T10 = For Record  T11 = FYI / Event / Miscellaneous  
RIA = Require Immediate Action
Appendix F

Value Assessment Survey Form
Web-based Information Logistics System (WILS) Research Project

The objective of this survey is to get a better understanding of the value to various parties involved in the USTL project. Please spend 5 to 10 minutes complete this survey.

Name ______________________________  Affiliation ___________________

PART A: General Questions (more than one box can be checked if applied)

1. How would you describe your role in the project?
   - Owner or Owner Rep.  □
   - A /E  □
   - G.C. / Prime Contractor  □
   - Subcontractor  □
   - Supplier  □
   - Other ___________________

2. How many projects are you currently working on (include USTL)?  _____ project(s)

3. How often are you on site?
   - I’m full-time on site.  □
   - Once a day  □
   - 2 to 3 times per week  □
   - Once a week  □
   - Once a month  □
   - Other ___________________

4. What type of internet connection do you have?
   - High-speed (LAN, Cable, DSL) at ___ Office       ___ Home       ___ On the road (laptop, PDA, etc.)
   - Low-speed (Dial-up) at ___ Office       ___ Home       ___ On the road (laptop, PDA, etc.)

5. How often do you access the WILS website?
   - Everyday  □
   - Almost everyday  □
   - 1 to 3 times per week  □
   - 1 to 3 times per month  □
   - Other ___________________

6. Rank the features that you find most useful from 6 (most useful) to 1 (least useful)
   - Real-time Still Image  ___
   - Still Image Archive  ___
   - Real-time Video (motion)  ___
   - Online Map & Direction  ___
   - Online Weather Forecast  ___
   - Other ___________________

7. For what purposes do you use the website?
   - Monitoring Work Progress  □
   - Material Delivery Planning  □
   - Quality Control  □
   - Security  □
   - Safe Work Condition  □
   - Weather Condition Monitoring  □
   - Productivity Analysis  □
   - Other ___________________

8. What additional online features would you like to have access?
   - Daily Work Planning  □
   - Message Board  □
   - Company Expertise  □
   - Drawing & Specifications  □
   - Humidity & Temp. Monitoring  □
   - RFI’s & Change Status  □
   - Visual As-builts  □
   - Real-time Equipment Status  □
   - Site Security System  □
   - Other ___________________
PART B: Feature Rating

1: Please rate the importance level for each feature range from 1 to 5 as follow:
   5 = Most important    4 = Very important    3 = Moderately important
   2 = Slightly important 1 = Little or no important

2: Please select the potential benefits for each feature (more than one box can be checked if applied).

<table>
<thead>
<tr>
<th>Rating</th>
<th>Feature</th>
<th>Potential Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Real-time still image Attributes: Outside building, cover staging area &amp; one side of the building</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>☐ Increase effectiveness of <strong>progress control</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td>☐ Increase <strong>productivity</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td>☐ Facilitate <strong>quality control</strong> process</td>
</tr>
<tr>
<td></td>
<td></td>
<td>☐ Increase work face <strong>problem solving</strong> efficiency</td>
</tr>
<tr>
<td></td>
<td></td>
<td>☐ Increase site <strong>safety &amp; security</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td>☐ Reduce <strong>work error</strong> due to miscommunication</td>
</tr>
<tr>
<td></td>
<td></td>
<td>☐ <strong>Savings</strong> due to reduced traveling time &amp; paper work</td>
</tr>
<tr>
<td></td>
<td></td>
<td>☐ Expanding <strong>team work</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td>☐ Attract more <strong>clients</strong> (marketing)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>☐ Other</td>
</tr>
<tr>
<td>1</td>
<td>Real-time site video image Attributes: Outside building, cover staging area &amp; one side of the building</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>☐ Increase effectiveness of <strong>progress control</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td>☐ Increase <strong>productivity</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td>☐ Facilitate <strong>quality control</strong> process</td>
</tr>
<tr>
<td></td>
<td></td>
<td>☐ Increase work face <strong>problem solving</strong> efficiency</td>
</tr>
<tr>
<td></td>
<td></td>
<td>☐ Increase site <strong>safety &amp; security</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td>☐ Reduce <strong>work error</strong> due to miscommunication</td>
</tr>
<tr>
<td></td>
<td></td>
<td>☐ <strong>Savings</strong> due to reduced traveling time &amp; paper work</td>
</tr>
<tr>
<td></td>
<td></td>
<td>☐ Expanding <strong>team work</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td>☐ Attract more <strong>clients</strong> (marketing)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>☐ Other</td>
</tr>
<tr>
<td>1</td>
<td>Real-time still image Attributes: Inside building &amp; focus on one particular location</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>☐ Increase effectiveness of <strong>progress control</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td>☐ Increase <strong>productivity</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td>☐ Facilitate <strong>quality control</strong> process</td>
</tr>
<tr>
<td></td>
<td></td>
<td>☐ Increase work face <strong>problem solving</strong> efficiency</td>
</tr>
<tr>
<td></td>
<td></td>
<td>☐ Increase site <strong>safety &amp; security</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td>☐ Reduce <strong>work error</strong> due to miscommunication</td>
</tr>
<tr>
<td></td>
<td></td>
<td>☐ <strong>Savings</strong> due to reduced traveling time &amp; paper work</td>
</tr>
<tr>
<td></td>
<td></td>
<td>☐ Expanding <strong>team work</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td>☐ Attract more <strong>clients</strong> (marketing)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>☐ Other</td>
</tr>
</tbody>
</table>
## Rating Feature Potential Benefits

<table>
<thead>
<tr>
<th>Rating</th>
<th>Feature</th>
<th>Potential Benefits</th>
</tr>
</thead>
</table>
|        | Real-time video image | Increase effectiveness of **progress control**  
|        | **Attributes**: Inside building & focus on one particular location | Increase **productivity**  
|        | | Facilitate **quality control** process  
|        | | Increase work face **problem solving** efficiency  
|        | | Increase site **safety & security**  
|        | | Reduce **work error** due to miscommunication  
|        | | **Savings** due to reduced traveling time & paper work  
|        | | Expanding **team work**  
|        | | Attract more clients (marketing)  
|        | | Other ________________ |
|        | Real-time still or video image from mobile camera | Increase effectiveness of **progress control**  
|        | **Attributes**: Capable of going anywhere on site & required no setup time | Increase **productivity**  
|        | | Facilitate **quality control** process  
|        | | Increase work face **problem solving** efficiency  
|        | | Increase site **safety & security**  
|        | | Reduce **work error** due to miscommunication  
|        | | **Savings** due to reduced traveling time & paper work  
|        | | Expanding **team work**  
|        | | Attract more clients (marketing)  
|        | | Other ________________ |
|        | Create time-lapse movie clip | Increase effectiveness of **progress control**  
|        | **Attributes**: site activity such as brick laying, windows installation, and greenhouses for particular period of time (1 day, 1 week, or the whole project) | Increase **productivity**  
|        | | Facilitate **quality control** process  
|        | | Increase work face **problem solving** efficiency  
|        | | Increase site **safety & security**  
|        | | Reduce **work error** due to miscommunication  
|        | | **Savings** due to reduced traveling time & paper work  
|        | | Expanding **team work**  
|        | | Attract more clients (marketing)  
|        | | Other ________________ |
|        | Create historical image archive & Visual As-built | Increase effectiveness of **progress control**  
|        | | Increase **productivity**  
|        | | Facilitate **quality control** process  
|        | | Increase work face **problem solving** efficiency  
|        | | Increase site **safety & security**  
|        | | Reduce **work error** due to miscommunication  
|        | | **Savings** due to reduced traveling time & paper work  
|        | | Expanding **team work**  
|        | | Attract more clients (marketing)  
<p>|        | | Other ________________ |</p>
<table>
<thead>
<tr>
<th>Rating</th>
<th>Feature</th>
<th>Potential Benefits</th>
</tr>
</thead>
</table>
|        | Automatic monitoring of site condition such as temperature, humidity,    | - Increase effectiveness of progress control  
|        | and water                                                               | - Increase productivity  
|        |                                                                       | - Facilitate quality control process  
|        |                                                                       | - Increase work face problem solving efficiency  
|        |                                                                       | - Increase site safety & security  
|        |                                                                       | - Reduce work error due to miscommunication  
|        |                                                                       | - Savings due to reduced traveling time & paper work  
|        |                                                                       | - Expanding team work  
|        |                                                                       | - Attract more clients (marketing)  
|        |                                                                       | Other  
|        | Real-time equipment status such as “safety” and “health”              | - Increase effectiveness of progress control  
|        |                                                                       | - Increase productivity  
|        |                                                                       | - Facilitate quality control process  
|        |                                                                       | - Increase work face problem solving efficiency  
|        |                                                                       | - Increase site safety & security  
|        |                                                                       | - Reduce work error due to miscommunication  
|        |                                                                       | - Savings due to reduced traveling time & paper work  
|        |                                                                       | - Expanding team work  
|        |                                                                       | - Attract more clients (marketing)  
|        |                                                                       | Other  
|        | Intermediate notification of change, RFI, drawing & specification      | - Increase effectiveness of progress control  
|        |                                                                       | - Increase productivity  
|        |                                                                       | - Facilitate quality control process  
|        |                                                                       | - Increase work face problem solving efficiency  
|        |                                                                       | - Increase site safety & security  
|        |                                                                       | - Reduce work error due to miscommunication  
|        |                                                                       | - Savings due to reduced traveling time & paper work  
|        |                                                                       | - Expanding team work  
|        |                                                                       | - Attract more clients (marketing)  
|        |                                                                       | Other  
|        | Project-wide material delivery schedule & procedure including date,     | - Increase effectiveness of progress control  
|        | time, route, and staging area                                         | - Increase productivity  
|        |                                                                       | - Facilitate quality control process  
|        |                                                                       | - Increase work face problem solving efficiency  
|        |                                                                       | - Increase site safety & security  
|        |                                                                       | - Reduce work error due to miscommunication  
|        |                                                                       | - Savings due to reduced traveling time & paper work  
|        |                                                                       | - Expanding team work  
|        |                                                                       | - Attract more clients (marketing)  
|        |                                                                       | Other  

<table>
<thead>
<tr>
<th>Rating</th>
<th>Feature</th>
<th>Potential Benefits</th>
</tr>
</thead>
</table>
| ____   | Automatic generation of daily report including worker, equipment, and weather condition | □ Increase effectiveness of **progress control**  
□ Increase **productivity**  
□ Facilitate **quality control** process  
□ Increase work face **problem solving** efficiency  
□ Increase site **safety & security**  
□ Reduce **work error** due to miscommunication  
□ **Savings** due to reduced traveling time & paper work  
□ Expanding **team work**  
□ Attract more **clients** (marketing)  
□ Other ________________ |