

**Wireless Communication and Computing
at the Construction Jobsite**

by

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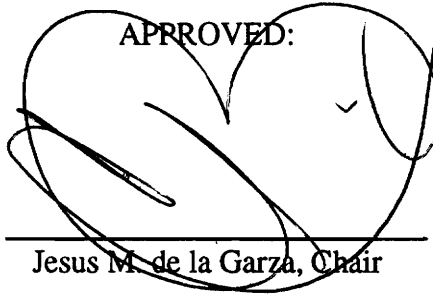
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WIRELESS COMMUNICATION AND COMPUTING AT THE CONSTRUCTION JOBSITE

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(ABSTRACT)

This thesis explores the information flow at a construction site and examines how wireless communication technology can meet these information needs. The construction industry is dynamic. Therefore, traditional methods of communication have limited applicability to a construction jobsite. However, the advances in the wireless communication field are making that form of communication a viable option for the construction jobsite.

The information flow models in some other industries are examined as point of comparison with the construction industry. People in the construction industry can learn what information transmission methods have worked in other industries. Also, much can be learned from other industries that have already embraced wireless technology into their workplace.

An articulation of information needs at a construction jobsite is made. A large refinery that is under construction in Houston, Texas was the primary a source for articulating the information needs at a construction site. A detailed summary of a data reconnaissance visit to this project is included.

A methodology for identifying determining the applicability of different formats of wireless technology for a set of information needs is included. A second methodology for identifying and classifying information needs by a given company is also included. Finally, two examples of how to use these methodologies are presented.

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Table of Contents

Chapter 1 Introduction	1
1.1 Problem Statement	1
1.1.1 Background	1
1.1.2 Statement of Problem	2
1.1.3 Benefits	3
1.2 Purpose, Scope and Objectives	4
1.2.1 Purpose	4
1.2.2 Scope	4
1.2.3 Objectives	5
1.3 Methodology	5
Chapter 2 : Other Industries' Information Models	7
2.1 Introduction	7
2.2 The Manufacturing Industries	8
2.2.1 The Volvo / General Motors Example	11
2.3 The Shipping and Trucking Industries	13
2.3.1 Federal Express (FedEx) and United Parcel Service (UPS)	14
2.3.2 The Trucking Industry	17
2.4 Conclusion	19
Chapter 3 The CII Research Team and Lyondell - Citgo Data Reconnaissance Visit.....	21
3.1 Introduction	21
3.2 Role of the CII Research Team	22
3.3 The Lyondell - Citgo Refinery Projects Visit	24
3.3.1 The Lyondell - Citgo Refinery Projects Visit - Overview	25

3.3.2 The Lyondell - Citgo Refinery Projects Visit - Questionnaires	27
3.3.3 The Lyondell - Citgo Refinery Projects Visit - Interviews	32
3.4 Compilation and Validation of the Information Needs.....	34
3.5 Conclusion.....	35
Chapter 4 Articulation of Information Needs	36 ✓
4.1 Information Needs Introduction.....	36
4.2 Different Formats of Wireless Communication to be Considered.....	39
4.2.1 Live Voice Communication.....	40
4.2.2 Live Video Communication.....	42
4.2.3 Batched File Communication	43
4.2.3.1 Batched File Communication : Small Files (< 5 kb).....	44
4.2.3.2 Batched File Communication : Medium Files (> 5 kb., < 100 kb.).....	45
4.2.3.3 Batched File Communication : Large Files (> 100 kb., < 1 Mb.)	46
4.2.3.4 Batched File Communication : Access to the Contractor's Network.....	47
4.2.3.5 Batched File Communication : Interactive Computer Application Communication (White Boarding)	48
4.2.4 Live Data Feeds.....	49
4.3 Information Needs Categories.....	50
4.3.1 Information Category: Request for Information	50
4.3.2 Information Category: Materials Management.....	57
4.3.3 Information Category: Equipment Management	61
4.3.4 Information Category: Cost Accounting.....	65
4.3.5 Information Category: Schedule and Means and Methods.....	69
4.3.6 Information Category: Jobsite Record Keeping.....	73
4.3.7 Information Category: Submittals.....	78
4.3.8 Information Category: Safety.....	81

4.3.9 Information Category: Quality Control / Quality Assurance (QC / QA).....	84
4.3.10 Information Category : Future Trends	88
4.4 Conclusion.....	91
Chapter 5 Framework for Technology Assessment	93
5.1 Information Needs Introduction.....	93
5.2 Framework for Wireless Technology Assessment.....	93
5.2.1 Information Needs Assessment and Summary	94
5.2.2 Restriction of Wireless Technology Based on Data Rate Requirements	97
5.3 Hypothetical Case Study #1	100
5.3.1 Hypothetical Case Study.....	100
5.3.2 Options to Hypothetical Case Investigated.....	104
5.4 Hypothetical Case Study # 2	112
5.5 Conclusion.....	119
Chapter 6 Summary and Conclusions	121 ✓
6.1 Summary	121
6.1.1 Summary of Information Needs Articulation	121
6.1.2 Summary of Methodology of Identifying Wireless Technology to Meet Information Needs	122
6.2 Conclusions.....	122
6.2.1 How the Construction Industry Can Benefit from Using Wireless Technology	122
6.2.2 When Not to Consider Using Wireless Technology	123
6.2.3 Importance of Cost Versus Benefit.....	124
Bibliography.....	127 ✓

Appendix A Questionnaire From LCR Data Reconnaissance Visit..... 129 ✓

Vita..... 140

List of Tables

Table 3.1	Lyondell - Citgo Refinery Projects and Companies	26
Table 4.1	Information Category: Requests for Information	52
Table 4.2	Information Category: Materials Management	59
Table 4.3	Information Category: Equipment Management	63
Table 4.4	Information Category: Cost Management	66
Table 4.5	Information Category: Schedule and Means and Methods	70
Table 4.6	Information Category: Jobsite Record Keeping	75
Table 4.7	Information Category: Submittals	79
Table 4.8	Information Category: Safety	82
Table 4.9	Information Category: Quality Control and Quality Assurance (QC / QA)	86
Table 4.10	Information Category: Future Trends	89
Table 5.1	Summary of Data Rates Required for Information Needs Articulated in Chapter 4	96
Table 5.2	Summary for Data Rates Required for Different Levels of Quality of Service	97
Table 5.3	Framework for Elimination of Wireless Communication from Consideration	99
Table 5.4	Information Needs That Have Been Identified for the Hypothetical Case	102
Table 5.5	Summary of Information Needs and Maximum Data Rate by Category for the Hypothetical Case	103
Table 5.6	Technical Aspects of Various Cellular Modems	108
Table 5.7	Technical Aspects of Various Wireless LANs	111
Table 5.8	Technical Aspects of Various CDPD Modems	119

List of Figures

Figure 4.1	Information Needs Charts' Headings	36
Figure 4.2	Data Rates (in kbps) Based on File Size and Delay Ratings	39
Figure 4.3	Comparison of Different Rates of Data Transfer	44
Figure 5.1	Layout of Site for the Hypothetical Sulfur Recovery Unit Example	101
Figure 5.2	Example of Articulation of Information Needs	114
Figure 5.3	Example of Articulation of Information Needs with Formats and Allowable Delays Included	115
Figure 5.4	Completed Information Needs Articulation Chart	116
Figure 5.5	Summary of Maximum Data Rates Required for Information Needs	117
Figure 6.1	Cost Benefit Comparison	125
Figure 6.2	Cost Benefit Example Two	126

Chapter 1 Introduction

1.1 Problem Statement

1.1.1 Background

The construction industry is very dynamic. It is a project-based industry. This dynamic atmosphere has provided an environment where the walkie-talkie has been common place on the construction site for over twenty-five years. These devices have allowed field personnel to communicate with management personnel in the job trailers to receive verbal instructions or make verbal requests. More recently, the personal pager and the cellular telephone have proliferated into the construction industry as their owning and operating costs have decreased. These devices are still limited in that they allow for verbal communication only. In order to receive more detailed, written, or graphical forms of data, the field personnel must physically go to the trailer, or trailer personnel must physically go to the field, to facilitate the information transfer.

Currently, the wireless communication industry is making significant advances in data communication. There are devices such as cellular modems, wireless LAN loops and other Radio Frequency (RF) communication devices that allow large amounts of data, written or graphical to be communicated wirelessly. These devices have the potential to greatly improve the flow of information between the trailer and the jobsite on a construction site. Because of the aforementioned dynamic nature of most construction jobs, the construction industry has the potential to reap great benefits from improvements in the flow of information through the use of these and other wireless devices.

The Construction Industry Institute (CII) has sponsored a project to help define the role of wireless technology in the construction industry. This document is being written in conjunction with this CII project.

1.1.2 Statement of Problem

The construction industry has relied on conventional paper-based forms of communication to disseminate information to personnel at the jobsite. Many functions that are office based have become automated through the use of computer technology. However, because it is impractical to lay conventional communication wiring from the trailer to the jobsite, the automation ends at the trailer. If information is needed in the field, it must be printed in hard copy and brought manually to the personnel in the field. The same holds true for the flow of information from the field to the trailer. For the most part, all information that originates in the field is generated in the hardcopy format. It is then brought to the trailer where it may be put into an automated format. The current situation is wrought with a large amount of duplication of effort and re-entry of information.

There is also a delay in the timely flow of the information. In the current jobsite communication paradigm, there is almost no information that is available to site personnel "on demand." If a piece of information is needed, the person requiring it must wait until someone can leave the work at hand and go to the trailer to get the hard copy of the information.

Wireless communication and data transfer technology have the potential to change this situation. It is or will soon be possible to transfer large data files such as CAD drawings or even full motion video in a timely manner through wireless mediums. If this data transfer capability were utilized by the construction industry it could be tailored to provide field personnel with almost any information that they might require in the field on demand.

1.1.3 Benefits

There are several benefits to incorporating innovative wireless technology solutions to the construction jobsite. First, and most obviously, is that wireless communication presents a dynamic solution for a dynamic industry. Wireless communication techniques do not require hardwiring. Therefore, it lends itself well as a method of communication that can work well at a jobsite despite the dynamic nature of construction industry.

Second, wireless communication has the potential to eliminate productivity that is lost while idle personnel wait for information to reach the field. All too often on construction jobsites, equipment and crews must stand idle while waiting for clarification, information, drawings or other instruction from the management in the trailer to reach them. Wireless communication has the potential to eliminate or at least ameliorate productivity that is lost while waiting for information.

Third, wireless communication has the potential to allow field personnel direct consultation with owner's reps, engineers, architects, or other consultants that cannot be on the site on daily basis. With some of the wireless video applications that are becoming available, concerned personnel will potentially be able to "look" at a problem on the site and recommend a solution in real time. This has the potential to decrease the number of site visits that involved professionals will need to make to the site. It is impossible to eliminate the need for these professional personnel from visiting the site altogether. However, wireless technology can allow such personnel to be more selective about when they visit the site, and to be better prepared to handle the problems or situations at hand when they do choose to visit the site.

Finally, the overall communication within a contractor's organization will be improved. Wireless communication has the potential to allow any party in the company to know what is going on at a jobsite at any given time. This technology has the potential to

eliminate replication of the same work and improve the overall flow and timeliness of information in a construction company.

1.2 Purpose, Scope and Objectives

1.2.1 Purpose

The purpose of this thesis is to identify what information needs to be communicated at the construction jobsite and to identify which of these needs can be met through current and emerging wireless communication technology. Also, to determine a methodology for the selection of current and emerging wireless communication solutions to the information flow problems that have been identified.

1.2.2 Scope

This document is limited in scope to identify only the information needs that are required between the jobsite and the trailer. Other communication needs (i.e. after information gets to the trailer) will not be considered as they can for the most part be handled through conventional hardwired technology. The data for the articulation of these communication needs was acquired from the Lyondell - Citgo Refinery (LCR) project near Houston, Texas.

This document two has primary objectives. First, it articulates the communication needs of contractors in the “last mile” (from the trailer to the jobsite and back to the trailer) at a construction site. Second, it shows a methodology that can be used to select current and emerging wireless technologies that might meet the information needs.

1.2.3 Objectives

This document has two objectives. The first is to identify information needs at the jobsite. This articulation of information needs comprises Chapter 4. The second is to develop a methodology for selecting possible wireless solutions that will meet these needs. This methodology is the subject of Chapter 5.

There are some other intermediate objectives that were accomplished in order to complete the two primary objectives. There was a significant study performed at LCR to gather data. Once this data was analyzed and articulated, it was sent out to various sources for validation. The details of this study and information validation are in Chapter 3. Some other industrial and organization information flow models are examined as a point of comparison. Chapter 2 discusses these information models. Additionally, two hypothetical case studies were made in Chapter 5 to illustrate the methodology that is suggested to use when looking at considering wireless solutions.

1.3 Methodology

The first step in the research for this thesis was a data reconnaissance visit to the Lyondell - Citgo Refinery. The LCR "mega -project" was selected as the primary source of data for the articulation of information needs by the CII research team because its scope was large and it had many information flow challenges as well as some wireless communication challenges due to the particular nature of the construction environment.

The following is a summary of some of the important facts about the LCR project:

- 1.2 Billion dollars in six contracts
- Two different prime contractors
- Construction taking place in the confines of working refinery
- Limited laydown space
- Major safety concerns

The data collected from the LCR data reconnaissance trip formed the basis for the information needs that are articulated in Chapter 4. The scope of the data collection was limited to that information that was gathered from the site visit to the LCR projects. Once the information needs were articulated, they were sent back to the personnel at LCR and to the CII project research team for validation and modification. The articulation of information needs was altered accordingly to reflect the modifications that were recommended during the validation phase.

The final step was to articulate a methodology for assessing the applicability of different formats of wireless technology to a given construction site. This methodology and two examples of how to use it forms the basis for Chapter 5.

Chapter 2 : Other Industries' Information Models

2.1 Introduction

There are many industries that have already incorporated communication systems into their respective work places. This chapter will take a look at some of these industries, and a few specific companies, in order to gain some insight into what has worked in other industries. The construction industry faces many different challenges than those that are faced by other industries. The construction industry will never be able to look at a model that works at another industry work place and apply it directly to the construction workplace because most other workplaces do not have the dynamic atmosphere that the construction industry does. However, many things can be learned by looking at other industries, and wireless communication technologies may make it possible to apply some of these ideas to the construction industry.

The manufacturing industry is similar to the construction industry in that they both start with raw material. Then through the use of equipment and labor, a finished product is made. Therefore, much of the types of information that a factory foreman might require at his work station might be similar to the types of information that a construction foreman might require while working in the field.

The industries that ship goods from one place to another is very different from the construction industry in most ways. They are similar in that they are both dynamic industries. In other words, they both move from one job to the next. The package and document shipping industries have made tremendous strides using wireless technology over the last few years. The construction industry might be aided in its implementation of wireless technology on to the jobsite by looking at how some wireless solutions have worked for the shipping industry.

In summary, the construction industry may benefit from taking a look at what has worked to improve the flow of information in other sectors and modifying and applying

these ideas to itself. The two different industries that will be examined in the subsequent pages were chosen because of their similarities in some ways to the construction industry.

2.2 The Manufacturing Industries

The manufacturing industries encompass a large portion of the economy in the United States as well as most of the other developed countries in the world. The manufacturing industry is in many ways the closest to the construction industry. Both industries start with nothing except an idea and eventually that idea is transformed into a tangible representation of that idea. In the manufacturing industries, that idea is usually reproduced very closely many times. Once the process of manufacturing the object is perfected, it can be repeated and each object that is produced will be made in the exact same way as the first and be nearly exactly the same. In the construction industry the idea is usually only made into reality once. There may be construction projects where the end results look alike. However, the process of building them usually are discernibly different.

Most manufacturing industries are process oriented. This means that a manufacturing company can concentrate their resources on refining and improving the process by which the given product is made. Once the first product is manufactured, the company can spend its time and resources to improve the process by which the product is being made. The basic manufacturing end product usually will not change that much over time. For example, an automobile manufacturer might change the looks or the features of a car but the end result will still be a car.

In contrast, the construction industry is project oriented. Every construction project is different from the previous one. This means that what might have worked well on one project might not work at all on another project. For many construction companies, a lot of time and resources are spent planning an individual project. This expenditure of resources will probably have to be completely repeated for the next project that the company undertakes because of the difference between the two projects. For

example, a construction company might win two contracts to build the exact same structure in two different locations. Much of the effort spent planning will have to be done separately for the two projects. Subsurface conditions might be completely different at the two locations. Labor arrangements might also be different. Just these two differences would cause the two projects to be built differently.

Most manufacturing industries are for the most part static. This means that in manufacturing industries the work place is fixed. Once a manufacturing facility is built, it usually does not move. This means that communication systems can be hardwired into the facility. This allows the manufacturing industry to use existing communications hardware as well as the existing communication infrastructure. In other words, a factory can have advanced communication systems throughout it without much of a challenge from the communication technology point of view.

In contrast, the construction industry is very dynamic. Each project that a construction company undertakes is at a different location. The site conditions will be varied from location to location. Even the workforce may need to migrate and change from location to location. The conditions at a project will even change as the project progresses. This dynamic nature of the construction industry puts it at a disadvantage in developing communication systems in relation to the manufacturing industries. A construction company cannot develop an elaborate hardwired communication system at a jobsite. They must be able to move their communication to the next location when they are finished. It must also be able to adapt to the changing conditions at a site as the project progresses.

Most manufacturing industries work in a controlled work environment. A factory has a roof over top and four walls around it. This means that the environment that the labor force works in can be controlled. This also means that a communication system may be installed into a factory such that the environment plays no role in the effectiveness of the communication system. The set up within a factory will not change drastically in a short amount of time.

In contrast, most construction sites cannot have any control over the environment. Most construction sites are outdoors, and are at the mercy of the elements. If it rains at a construction site then most work ceases; if it is cold, work slows down or ceases completely. The uncontrolled environment is another factor that must be considered when installing a communication system. The communications system must not only be portable but it must also be rugged enough to withstand the elements at a construction site.

One other way that the two industries are similar and different is the way that materials are handled and stored. Both industries require that raw materials need to be brought to the place of assembly and often times stored until they are needed for assembly. In the construction industry, once a product is assembled, or the project is completed, it is handed over to the owner for occupancy. In contrast, in the manufacturing industries, once the product is assembled, it usually needs to be shipped to the person that is purchasing it. This means that the completed product might also need to be stored before it is shipped. The manufacturing industries not only need to maintain control over their raw materials but they also may need to maintain control over their completed products.

Despite these important differences, the type of information that might be needed by someone on a factory floor are in many ways similar to the type of information that might be needed by someone working at a construction jobsite. Wireless technology is becoming advanced enough to serve as a conduit for the communication of information in the difficult parameters that a construction site might have. Therefore, the construction industry might be able to use many of the communication applications that are being used in manufacturing industries using hardwired communication techniques.

The following section looks at a manufacturing company that is in the process of implementing information communication systems. The example that will be investigated is a communication system that is being implemented at a truck plant that is operated by Volvo and General Motors.

2.2.1 The Volvo / General Motors Example

Volvo and General Motors (GM) operate a facility that manufactures large tractor trucks in Dublin, Virginia. The plant is a large operation that assembles the trucks. All of the components, including the bodies and the engines are manufactured elsewhere and shipped to the Dublin plant for assembly. The plant presently operates one production line and is in the process of constructing another. On this production line, the truck moves from one assembly station to another. Each station is responsible for installing the same pieces on each truck. When the one current line is operating at full speed, the factory can produce over ninety trucks in one hour. The plant has over 2000 employees that man the lines while production is underway.

All of the trucks that are built at the Volvo / GM plant are ordered by customers directly, or by dealers., Therefore, all of the vehicles that are produced are manufactured to the customer's specifications. Volvo / GM offer a few basic body designs with many different variations, but all of the trucks that they produce start with the same chassis. This means that when a new truck is started on the line, there are a set of paper specifications and drawings that are attached to it that travel with it throughout the line. This set of specifications show what variations to the basic design that need to be made to that given truck. The foreman at each station check the section of the specifications that are relevant to his own station and instructs his crew accordingly. The crew then installs the necessary parts. The truck stays at each work station approximately six minutes.

Volvo / GM maintains a design team in the same factory facility. The design team takes a given customer's order and produces the necessary drawings and specification which are sent to the plant floor for assembly. There are over forty different systems in a given truck that can be modified to meet an individual customer's needs. These include things as large as the engine size and cab type to thing as small as the color of the cab and type of radio to be installed. Once a customer places an order, it goes to a CAD team that

produces a complete CAD model for each truck that is ordered. The model is the basis for the paper drawings that travel with the truck while it is on the production line.

Volvo / GM was planning to install computer terminals at each of the stations on the assembly line. These terminals would be hardwired into the plant's computer system. The foreman of each crew would be able to look at the CAD model or portions of it for any given truck that came down the line. This would be in addition to and eventually in place of the paper copy of the drawings and specifications that currently travel with the truck. This means that the given foreman would be able to access the information that his crew needs faster and more efficiently than with the paper work alone. The foremen on the floor were to have read only capability to view the drawings. In other words, they would not be able to alter the drawings. However, there were plans for the foreman to record any changes, modifications or concerns about a given vehicle while it is on the line. These changes, modifications or concerns could then be addressed after the vehicle left the line. This is to prevent the line from having to stop.

The construction industry has similar processes and information needs at the jobsite. A crew foreman, at a construction site is usually given paper copies of the drawings and sometimes the specifications for the tasks that his crew are to perform. A construction foreman would benefit in the same way that a truck assembly foreman would by the information presented in an electronic format. They would be able to quickly look at different views of the drawing, and they would not have the clutter of paper. Also, a construction foreman could record as built changes to the plans in the same way that the truck assembly foreman would record his modifications or changes to the truck. Additionally, a construction company could impose the same 'read - only' requirements so that a foreman could not change the original plans.

The personnel at the Volvo / GM plant also thought that although the computer terminals would initially be used to communicate plans and specifications, eventually, they might be used for other communications purposes. Once the wiring is run, the capacity of such an information communication system can be expanded to include many other

applications like reporting that materials are running short or that a particular truck had a problem.

There are other forms of communication that are already in place at the Volvo / GM plant. Just about every station has a telephone that is wired for communication within the plant. If a foreman needs to inform someone of a problem or other situation that might need attention, they need not leave their station. If an emergency needs to be reported, it can be done rapidly. This means that the crews are constantly supervised. This seems to be important to insure that each crew performs all of their tasks in the allotted six minutes, before the truck moves on to the next crew.

The Volvo / GM truck plant in Dublin provides a few information communication ideas that might be incorporated into the construction industry. The means of communication will necessarily be different in the construction industry than in a truck plant. Wireless communication will play an important role in making possible this type of communication at a construction site. However, it is important to remember that although the means of communication will be different in the construction industry than in a truck plant, the type of information may be the same.

2.3 The Shipping and Trucking Industries

There are some industries that face the challenge of being dynamic in nature, like the construction industry. The shipping and trucking industries are two examples that will be considered in this section. Both of these industries are already incorporating wireless communication to meet some of their information flow needs. The information needs of these two industries are mostly different than the needs of the construction industry. However, they can be looked to as examples of how wireless technology has been incorporated into other industries.

The shipping industry's primary goal is to move parcels from one location to another. In order to remain competitive, shipping companies must maintain tight control

of tracking the packages that they are moving. It would be difficult for a shipping company to stay in business if it had a reputation for losing packages on a regular basis or not knowing where they are at a given point in time. Therefore, many of the shipping companies are using wireless technology to track packages from the time they are picked up from the shipper until the time they are received. The next section will look at the use of wireless communication system in Federal Express and the United Parcel Service.

The trucking industry is another where tracking is important. Some trucking companies have several hundred trucks on the road at a given time. A single truck can carry up to seventy thousand pounds of goods at a time. This means that each truck that a company has on the road is carrying a lot of goods for their customers. Logistically, it is important for a trucking company to know where its trucks are at a given time. Therefore, the trucking industry has started using Global Positioning Systems (GPS) to track its trucks that are on the road. The trucking industry will be examined in the second half of this chapter.

The construction industry might not learn much about its own information needs by looking at these two industries. However, the lesson that might be learned is that wireless communication is already being used in other industries that face some of the same location problems that it faces.

2.3.1 Federal Express (FedEx) and United Parcel Service (UPS)

Federal Express and the United Parcel Service represent two of the largest companies in the shipping business. They both offer overnight delivery of packages as well as longer shipping options. UPS claims to deliver over eleven million items each business day (UPSWWW) while FedEx claims to deliver over two million packages each business day (FEDWWW). There is a tremendous amount of planning and logistics issues that both of these company's address in order to insure the quality of their service. Both of these company's realize that they must maintain a commitment to customer service.

Most people who ship an item do not care much about the process involved in getting the item from point A to point B. They are more concerned that it gets from point A to point B in the time promised. Consequently, both of these companies make a major effort in ensuring prompt and accurate delivery of the packages.

They are both committed to finding solutions to the challenges that they face through excellent personnel and technology. One of UPS's credos is "an efficiently engineered system operated by quality people" (UPSWWW). FedEx believes that as technology improves, their service can improve if they can implement technology to their advantage. FedEx has recently commenced construction of a large technology center outside of Knoxville, Tennessee. This center will be dedicated to improving their employees familiarity with existing technology as well as looking for ways to incorporate new technology into their system. Dennis H. Jones, a senior vice president with FedEx, said, "Technology innovations happen at a rapid pace, it is crucial that our employees have an environment conducive to the accelerated pace of technology" (FEDWWW). UPS is planning on spending 3.2 billion dollars in the next five years on technology improvement (UPSWWW).

One field of technology that both companies are using is cellular technology. When a package is picked up, the driver records the information about the package and records its tracking number in a hand held device. This information is sent to the company's computer via a cellular data transmission system. From this point forward, the customer can track the package and find out where it is with the tracking number. Every time the package enters a new location its position is updated in the tracking computer. When the package reaches its final destination, the driver records the name of the person who received it and the time that it was signed for. Again the driver sends this information using a cellular data transfer system back to the company's computer. This allows for accurate tracking to take place.

Most of the updating of the location of a package for tracking purposes is done using standard hardwired technologies. It would not make sense to use wireless

technology when a package is being unloaded from a truck at a warehouse where hardwiring a communication system is not a challenge. However, wireless technology is used in the portions of a package's trip where hardwiring communication lines is impossible. By using wireless technology, they can have information updated as it happens. Once a package is delivered, the driver uses his hand held computer to record it as such. Once he returns to his truck, he can download the information in the hand held computer using a cellular modem in a base station in the truck. If wireless technology were not employed, they more than likely would not be able to send an update after each delivery because the driver would need to use a public telephone to send an update. Therefore, it might be several hours after a package is delivered, before the party that sent it could verify its receipt.

Federal Express offers a software package that allow a given company to be able track a package throughout the course of delivery. FedEx offers a program called Fed Ship™ that allows their customers to meet most of their shipping needs from their computer. The tracking capability allows the user to check the status of their packages. If a customer has Internet access, both companies have World Wide Web locations where a customer can simply enter the tracking number of their package and be updated with the package's status at that point in time. Wireless communication technology is an important part of the system that makes this tracking possible by providing up to the transmitting up to the minute information of where a package is located.

UPS has its own satellite for information communication. They have a global information network that the satellite is an important part of. This information system tracks the international shipping that UPS does. This satellite communication system is another example of how wireless technology is being used to meet the information needs in the shipping industry.

In conclusion, Federal Express and the United Parcel Service are both incorporating wireless technology into their workplace to meet some of their information flow needs. The shipping business operates in a dynamic setting, much as the construction

industry does. Federal Express maintains a fleet of 37,000 vehicles that are moving from one location to another throughout the course of a business day. Because of the constantly changing locations that the driver are in, wireless technology has become an important means of information communication in the shipping business. It is used to bridge the gap in the 'last mile' of their communication systems, where hardwired technology is impossible.

2.3.2 The Trucking Industry

There is a move in the trucking industry to incorporate the Global Positioning System (GPS) and communication satellites into the industry. The trucking industry is very dynamic, most of its resources are in motion at any given point in time. Even a smaller trucking company might have difficulty keeping track of its trucks are at any given point in time.

Some trucking companies have experimented with using cellular telephones as a means of keeping contact with their trucks while they were on the road. They ran into several problems using cellular. First, there are still many areas in the country that do not have cellular service provided. When a truck would enter such an area, a cellular telephone would become useless. Second, a dispatcher is still dependent on driver calling in to update his location. If the driver only checked in every eight hours a good distance could be covered between check ins. Finally, service fees for cellular phones can become expensive. If a driver left his service provider's area, any call that he would make would be subjected to roaming charges that in some areas are very expensive. Also, drivers would use the phones for personnel uses and the trucking company would have to pay for the calls [WHI96].

Many trucking companies are looking to use the GPS and other satellite dependent communication systems to improve their communication. There are two primary information needs that the trucking industry has. First, they need to know the location of

their trucks so that they can update their customer's on delivery times. Second, they need to be able to send the drivers updates of any problems or situations that arise during his trip. It is important if it became necessary for a truck to change its route or destination.

One trucking company that has already incorporated the GPS and satellite communication into its fleet is Day & Night Transportation Services, based in Noblesville, Indiana. They have outfitted about half of their trucking fleet with GPS and satellite communication capabilities. Using the GPS, dispatchers at Day & Night's headquarters can locate where their trucks are at any point in time, anywhere in the world. This allows management more flexibility in scheduling and routing their trucks [WHI95]. For example, if a truck breaks down, dispatchers might be able to locate another truck close by that had just unloaded a trailer. If the dispatchers were able to get in contact with the second truck, they would be able to direct the driver to go to the first truck and pick up and deliver its trailer.

Satellite communications also plays a part in the Day & Nights system. Each truck is outfitted with a data terminal that has a keyboard and an LCD display screen. The driver of each truck can send and receive text based messages that are sent via satellite using the data terminal. Day & Night use two different communication network's to accomplish this. First, they use the land-based ARDIS network where it is available. ARDIS is a form of packet switched specialized mobile radio. If the truck is in an area where ARDIS is not available, the message is relayed to the driver through American Mobile Satellite Corporation's geosynchronous satellite. This solves the problem of how to get in touch with the driver.

The system that Day & Night is using also ties to their accounting and logistics programs. Once a driver delivers a load, he can update the computers at the headquarters without having to contact a dispatcher. He can record deliver of his goods and the company's computer will be updated to reflect this.

This is another example of how an industry is finding solutions to its information flow challenges through wireless technology. One of the goals of the trucking industry is

“to maximize each truck’s drive time while minimizing the miles that it travels” [WHI95]. Day & Night articulated what information needs that it had and then went out to look for solutions. It first tried cellular phones as a possible solution but then discovered some of its short comings. It then turned to satellite communications and has found a system that can meet most of its information needs. The construction companies may want to look at some of the lessons that Day & Night learned. First, they invested in technology without looking at some of its possible short comings. Second, once they articulated and thought through their information needs they were able to find an applicable technology to meet their needs better.

2.4 Conclusion

This chapter examined the information needs of two industries outside of construction. It also examined the technologies that these industries use to meet their information needs. The manufacturing industry was chosen because of its many similarities to the construction industry. The shipping industry was chosen because it has already implemented and is becoming dependent on wireless technology to meet its information needs.

A construction company changes its locations every time it start or completes a job. Even in the confines of a jobsite, the topography change often. This means that it would be difficult and costly to install hardwired communication beyond the trailer at a construction site. If a company did want to establish communications between the field and the trailer using conventional hardwired methods, there would be an initial expense laying the wire. However the larger expense would be incurred in moving and maintaining the line. This is why wireless communication is being considered as a means to facilitate communication between the trailer and the jobsite on a construction site.

The manufacturing industry has many of the same information needs that the construction industry does. Many of the processes are the same between the two

industries. The manufacturing industry has the benefit of working in a mostly static environment therefore it can take advantage of using hardwired communication to meet its information needs. In looking at an example like the Volvo / GM plant, someone in the construction industry can see similarities in the types of information that a manufacturing plant and a construction site have.

The shipping industry is one that is already making use of some of the wireless technology that is available. The types of information that the shipping industry needs to flow are different from the construction industry. However, by looking at companies like Federal Express, and the United Parcel Service, one can see how important the role wireless technology has become in their businesses. The trucking industry, exemplified by Day & Night is also becoming more dependent on wireless technology to meet its information needs.

In conclusion, the construction industry will in all likelihood will benefit from by the incorporation of wireless technology into its jobsites in the future to meet its information needs. The construction industry does not have to look too far to see other industries that have similar information needs as well as other companies that are successfully using wireless technology already.

Chapter 3 The CII Research Team and Lyondell - Citgo Data Reconnaissance Visit

3.1 Introduction

One of the goals of the Construction Industry Institute's (CII's) wireless communication project was to articulate information needs at the construction site that could be met using wireless technology. This chapter will discuss the methodology and reasoning that were employed to gather, compile and validate the information needs that are presented in Chapter 4 of this document. There were several phases in the information gathering process and this chapter will examine each of them.

The first phase was conception and planning. The CII research team, discussed in Chapter 1, was the guiding force in shaping the direction that the project took. They defined the three goals of the project: the articulation of information needs, the survey of wireless technology and matching needs to technology. They were also responsible for choosing the Lyondell - Citgo Refinery project as the primary source for data collection. The research team members also played an important role in compiling and validating the information needs.

The data reconnaissance visit to the Lyondell - Citgo Refinery (LCR) took place in March, 1996 when it was visited by a data reconnaissance team. There were several phases of different projects under construction while the team was there. The team distributed a questionnaire to personnel, as well as conducted interviews with them. The information collected there became the primary basis for the articulation of information needs contained in this document.

The information needs that were arrived at were analyzed at one of the CII research team meetings. There were some changes and revisions made as a result of this discussion. After these revisions were made, the articulation of information needs were sent to all of the CII research team members who used contacts that they had in the

construction industry to help verify and validate the information needs that were presented. The validation process was included to ensure that the information needs that were included were important, as well as to keep some important information need from being excluded.

This chapter will examine in some depth the processes and methodologies that were used during the gathering and distillation of information in this project. Sections will examine the following:

- The CII research team's role in the information process.
- The data reconnaissance visit to the Lyondell -Citgo Refinery projects.
- The compilation and validation of the information.

3.2 Role of the CII Research Team

The Construction Industry Institute formed a team to research the applicability of incorporating wireless technology into the construction industry. The members of the research team work for companies that are members of the Institute. There are presently members of the research team. The following is a complete listing of the members:

- Alan Waldbusser, Research Team Chairman, TPA Associates
- Mikkel Hansen, Texaco Corporation
- Joseph St. Julien, H. B. Zachry, Inc.
- John Bennett, H. B. Zachry, Inc.
- Dr. William Stone, National Institute of Standards and Technology (NIST)

There are two Virginia Tech faculty members who are also on the research team, Dr. Jesus M. de la Garza, Associate Professor in Construction Engineering and Management Division of the Civil Engineering Department and Dr. Ivan Howitt, Visiting Professor in the Mobile and Portable Radio Group (MPRG) of the Electrical Engineering Department. This research team has guided the direction and format of the research in this project.

The research team's initial meeting was in January, 1996. The results of this meeting were to set the goals of the research. The three goals established that have been discussed previously. The ideas and goals that were discussed at this meeting were also the basis for the formal proposal that was submitted to CII. At this occasion the research team also decided that the Lyondell - Citgo Refinery projects, in Houston, Texas, would be an ideal construction site to gather data for this study. There are two team members that are employed by H. B. Zachry, who had three contracts at the LCR site.

The second meeting of the research team took place in February, 1996. The team decided what type of information should be gathered at the visit to the LCR projects. The type of questionnaire to be used was also discussed. The dates for the visit were finalized and Mr. Bennett was appointed to coordinate the visit at LCR. The research team also discussed other issues involving the finalization of the project.

The data reconnaissance visit to the LCR projects took place from March 11 through March 13, 1996. Information concerning the visit is contained in Section 3.3. Virginia Tech sent two representatives to conduct the data reconnaissance, Dr. Howitt and a graduate student from the Construction Engineering and Management division. During the visit the team was assisted by Mr. Bennett, who played an important role in facilitating meetings and interviews.

The third meeting of the research team took place in April, 1996. This meeting was used to determine what the output from the project would be.

The fourth meeting took place in May, 1996. This meeting was to review the work that had been completed to date. The two groups from Virginia Tech presented their research to date. The research team made comments and suggestions for changes, modifications and revisions. They helped to finalize the information needs categories that appear in Chapter 4. Finally, they agreed to help validate the information needs in their organizations.

The work of this research team will be presented to CII in September, 1996 in Austin, Texas. The work that is being presented in this thesis will be presented in conjunction with the work of the MPRG as the output of this CII research team.

3.3 The Lyondell - Citgo Refinery Projects Visit

The Lyondell - Citgo Refinery projects were chosen by the CII research team as a primary source for this study. The subsequent sections will discuss the project itself, as well as how information was gathered there. The project is a renovation and expansion to a working crude oil refinery. The research team chose this site for several reasons.

First, and possibly foremost, H. B. Zachry was a prime contractor at the LCR. H. B. Zachry is a member of CII and had two representatives on the CII research team. Both of these representatives spent some time working at the LCR. This gave the data collection team a point of contact at the project to coordinate and facilitate the visit. At the time of the visit Mr. Bennett was still working at one of the Zachry sites in the LCR project. Mr. Bennett spent many hours in arranging and hosting the data collection team. If the team had not had a contact at the site they probably would not have been able to accomplish as much as they did in such a short time. Additionally, Zachry has already started to do some work with advanced wireless hardware on their sites. Mr. Bennett has done some of the work for Zachry in this area which was an added benefit for the choice of LCR as a source for data.

Second, the LCR was chosen for its complexities as a construction project. The construction was taking place within the confines of an operating refinery. There were several projects under several different contracts. The research team felt that many information needs would be revealed at this project because of its size and complexity.

Finally, since the construction was taking place within the confines of a refinery, it was felt that some of the challenges for wireless technology would be revealed as well. The different construction sites were spread out over several miles. Most of the sites had

large metal structures and pipelines throughout them. For these and other reasons, the research team felt that the LCR site would be a good indicator of some of the conditions that might affect wireless technology.

The rest of this section will address the data reconnaissance team's visit to LCR. There is a section which discusses the project, its scope, and some of the challenges that the contractors have had to face. The next section will discuss the questionnaire that was used. It will look at the positives and negatives of the questionnaire and its administration. The final section will discuss the interviews that were conducted. The section will discuss the format of the interviews as well as the positives and negatives of them.

The LCR data reconnaissance visit revealed many of the challenges that contractor's face getting information to and from the field. The personnel at LCR were all very courteous and helpful to the data reconnaissance team during their visit. The information that they produced was very relevant and is the basis for most of the information that is contained in Chapter 4 of this document.

3.3.1 The Lyondell - Citgo Refinery Projects Visit - Overview

The Lyondell - Citgo Refinery (LCR) project involved the construction of several new facilities in the confines of an existing and operating crude oil refinery. This project was estimated to have a price of 1.2 billion dollars. Citgo, the project owner, used several negotiated "Cost - Plus" contracts with several contractors to build this project. There were five main units (areas of new construction) that were divided between two prime contractors. The five units, with the prime contractor constructing each unit, are listed below:

Table 3.1 LCR Projects and Contractors

UNIT	PRIME CONTRACTOR
Hydrotreater Unit	H. B. Zachry
Crude Unit (CU)	H. B. Zachry
Sulfur Recovery Unit (SRU)	H. B. Zachry
Coker Unit	S & B Construction Company
Revamp Unit	S & B Construction Company

Additionally, both of the prime contractors maintained significant off-site operations to support their efforts on site. Between the two contractors, it was estimated that there were a total of over 4500 construction workers on the site.

LCR had a significant Project Management Team (PMT) that was on site. The new facilities were primarily designed by Bechtel, who also played a major role on the PMT. Most of the rest of the PMT were employees of Citgo. Since it was a cost-plus job, all expenses incurred by a contractor had to be submitted to the PMT for reimbursement from the owner. This meant that accurate records and time sheets were of the utmost importance to both the owner and the contractor, since those were the basis for all payments. Most of the materials for the job were procured directly by the PMT.

The data collection team was able to spend time at all three of the H. B. Zachry units as well as their off-site location. The team was also able to spend time at the S & B off-site location for the study. The other two S & B sites were on twenty-four hour shifts and time could not be spared by the personnel at these sites to participate in the study. It seemed that most of the units that the team visited were reaching or had reached critical times in their construction. Most of the people that the team spoke with seemed to be under a lot of pressure. The team's host on site, Mr. John Bennett from H. B. Zachry, was located in the Hydrotreater unit, and as a result the team spent a good amount of time there. The team was also able to have an in depth tour of this unit.

To give an idea of the scope of the work, the Hydrotreater unit seemed to be the smallest of the five units. The construction was taking place in an area that was about 770' long and 350' wide. The site was only accessible from one of the long sides. The other three sides were enclosed by working areas of the refinery. There were three major (over four story) steel structures that were being constructed as well as a tremendous amount of pipe installation being done. There are going to be over 4500 spools (sections) of pipe that will be installed when the unit is completed. The project started in January 1995 and was scheduled to be completed in June, 1996. At the time of the visit, the completion of the unit had been postponed to August, 1996. Zachry had over 800 people working at this unit working in a ten-hour shift.

The team was unable to get in depth information from any of the other units. Most of the information that the team got about the Hydrotreater was obtained from Mr. Bennett.

There are a few other items that are noteworthy that will be discussed here. Safety was the number one priority of everyone at the LCR. LCR set very high safety standards for everyone in the refinery. These standards were adhered to without question. Zachry had an even tighter set of safety standards within their units. Zachry had a safety staff and even "safety monitors" that roamed the units to look for unsafe situations.

One other item that bears mentioning is that there seemed to be tension between the PMT and the contractors. It seemed that there were some problems in the information flow between these two entities. In some of the interviews there seemed to be some animosity between the PMT and contractors.

3.3.2 The Lyondell - Citgo Refinery Projects Visit - Questionnaires

There are several important things that need to be mentioned about the questionnaires and the methodology used in distributing them. First, it was agreed upon at

the second CII research team meeting that it was important to try and keep the questionnaire itself from biasing the responses. The questions were formatted in such a way that it allowed for open ended answers to some extent. There were essentially three categories of questions contained in the questionnaires (a copy of the original questionnaire is included as Appendix A), they are as follows:

- 1.) **Background and Categorization Questions** - These were to determine the nature of the respondent's background, their role in the current project and their overall background in the construction industry. There were also questions designed to ascertain any previous exposure that the respondents have had with wireless technology and applications. These questions were designed to help qualify the answers to the subsequent questions.
- 2.) **Data Elicitation** - There were three sections of the questionnaire that were for data elicitation. These were the main areas from which relevant data was desired. These questions were presented in a tabular format. It was felt that this format would be easiest for the respondents to follow. There were three questions used for data elicitation. The first was used to try and determine areas that could be improved by better information flow. The second was used to determine what data needs could be met by different methods of wireless data transmission. The third question was used to find out what methods of data transmission the respondents would be most comfortable using for different tasks.
- 3.) **Open Response** - The final type of question was open ended so that the respondents could make any comments or other suggestions that they might have had that were not covered specifically in the other questions.

One issue that is important to mention is the distribution of the questionnaires. The data collection team distributed the questionnaires to the respondents personally for

the most part. The team gave a brief introduction of who they were and what the survey was about. Then the team stated that the questionnaire was to assess information needs between the field and the job trailer. The team answered any specific questions that the respondents had, but did not give any further information. This limited information approach was used in an effort to minimize any biases that the respondents might have gotten from the data reconnaissance team. The team did think that it was important to answer any questions that the respondent might have had, to encourage better output in spite of the fact that it might bias responses.

Overall, the reaction to the questionnaire was quite positive. Most of the parties that were interviewed seemed to be quite interested and willing to participate. There were even some that were extremely positive and excited about the ideas that were being relayed. There were also some people that took a negative view of the questionnaire and questionnaires in general. There was only one individual that the team approached who refused to take a questionnaire. There were, however, many people that took questionnaires that did not fill them out or return them to the team or to Mr. Bennett subsequent to the team's departure.

While the team was at the LCR sites, they distributed approximately forty questionnaires in the course of two and a half days. When the team left on the third day they had received 16 completed questionnaires. There were two points of contact established for collection and return of any questionnaires that were completed after the team left. Mr. John Bennett of H. B. Zachry and Mr. Sam Beckworth of S & B were these two contact points. They agreed to send any subsequently completed questionnaires to Virginia Tech. There were only a few questionnaires received by the team since their departure.

During the time that the team was at the LCR sites in Houston, they realized that the questionnaire itself had some flaws. The following is a list of these problems as well as some suggestions that could have improved them:

- 1.) There was no mention of who was conducting the survey nor was a return address given anywhere in the questionnaire.

This could have been prevented by including Virginia Tech at the bottom of every page and a return address could have been included on the first and the last page of the survey.

- 2.) The ordering of the questions was also a problem. Some people who were taking the survey got to the fifth section, (the section that asked for their comments and thoughts) and believed that it was the end of the questionnaire. Therefore, they did not look at nor complete the final question.

The last question was added to the questionnaire after it had been printed. Rather than redo the entire printing of the survey, it was added to the end. If the question had been put before the printing or if the survey had been reprinted, some confusion might have been avoided.

- 3.) The third problem did not occur to the team until after the first day. Several of the respondents said that they did not understand how to answer some of the questions. That they were not sure of how the tables should be filled in. Upon further review of the questionnaire by the team it was seen how easily some of the tables might become confusing, in spite of the fact that example responses were given.

The problem could have been avoided by changing the methodology that was employed for distribution of the questionnaire. If the team had explained each section of the survey and the types of responses that they were looking

for, much of this confusion could have been eliminated. This probably could be done without biasing the survey very much.

- 4.) The questionnaire did not contain anywhere for the respondents to include whom they worked for. This was not noticed until after the team sorted the completed questionnaires. This information would have been useful in helping to identify what point-of-view that each respondent had and any biases that those different points-of-view might have.

The confusion could have been avoided by having questions that would have identified for whom and where each of the respondents worked.

- 5.) The final problem is a more fundamental one than the previous four problems. The team felt that they were catching some of the respondents somewhat off guard. In most cases, when they arrived in these person's offices, it was the first time that they had heard about this study. It seemed that if the respondents had been given more time to think about the survey, better results might have been achieved.

There are two ways that this area might have been improved. First, the surveys could have been sent to LCR a week before the team arrived. If proper coordination could have been arranged for them to be distributed, the respondents would have had an opportunity to look at the questionnaire and possibly had time to complete it before the arrival of the team. Second, if there had been better coordination with people at the LCR sites ahead of time they might have been thinking more along the wireless lines.

In conclusion, the questionnaires played an important part in the information gathering process despite the fact that they had some problems. The information that they produced became one of the main sources for the information needs that are articulated in Chapter 4.

3.3.3 The Lyondell - Citgo Refinery Projects Visit - Interviews

There were a series of interviews that were conducted primarily after the respondents had an opportunity to look at or complete the questionnaire. The interviews were very informal. The team wanted to generate as much open and interactive dialogue as possible. The interviews ranged in participation from one person to six people plus the data collection team. Generally, the team started the interviews by putting a few of the wireless technology applications on the table for discussion. The team tried to facilitate conversation as much as possible without taking the lead. It was the intent of the team to have most of the discussion in the interviews come from the interviewees.

Most of the interviews ranged from thirty to ninety minutes in duration. The amount of time spent was usually in direct proportion to the number of people being interviewed (the more people, the longer the duration). However, that was in no way a set format, it was just the way that things happened. In each different interview the direction varied, however, the team tried to keep the conversation from straying away from information needs and wireless communication. Often times, respondents wanted to tell the team everything that was wrong with information flow at the site. The team tried to limit this type conversation, but several beneficial ideas came from some of these digressions.

During the last half day that the team was at the LCR sites, some of the interviews had to be conducted concurrent with the distribution of the questionnaire. This was in the interest of time. By the third day, the team believed that more beneficial information was coming from the interviews than from the questionnaires. Rather than forfeit the

interviews for the sake of keeping the questionnaire unbiased, the team decided that it would be better to conduct the interviews and instill whatever biases they may.

The reactions of all those interviewed were primarily positive, both towards doing the interview and the content of the interview. No one, that was interviewed thought that the study, or the application of wireless technology to the jobsite was a waste of time. The main area of disagreement came from the discussions of what level of wireless technology would be appropriate in a construction setting.

It seemed that all of the participants that were interviewed recognized the need to incorporate better communication on the jobsite. Most were eager to help because many of the ideas that were discussed in the interviews would have a fair amount of impact on most the tasks that they performed.

Overall, there were not many problems with the interviews. For the most part there was good interaction between the data collection team and the interviewees. As stated before, the interviews were unstructured. This allowed for a very free exchange of ideas . A list of the concerns about the interviews follow along with ways that they might have been avoided.

- 1.) There were no preset questions that the team asked in the interviews. This meant that different information was obtained during the different interviews.

The team could have been to have a set format with several questions that were to be asked by the team in the course of the interview. This unstructured format did however have many positive aspects in that many different avenues were explored.

- 2.) During some of the interviews the conversation digressed from the subject at hand to other communication problems that existed. The interview team did not want to stifle any of the conversation, therefore they tried to bring

the subject of conversation back to wireless subtly. However, this approach did not always work.

The team could have had a third party act as a moderator. Mr. Bennett played this role to some extent during most of the interviews. If his role could have been pre-planned, he might have been able to effectively steer the conversation away from extraneous issues back to the focus of the study without causing anyone to not want to participate.

In conclusion, the interviews were an extremely important aspect of the data gathering. The data collection team gained a lot of insight into some of the communication challenges that a large construction site faces. The participation and enthusiasm of the interviewees showed that there is an interest at all levels at a construction jobsite to have better communication, through wireless communication or other means.

3.4 Compilation and Validation of the Information Needs

Upon the completion of the site visit to the Lyondell - Citgo Refinery projects in Houston, the information that was gathered was compiled and classified into eight information categories. This number was subsequently expanded to ten. The information was further compressed into subcategories. Every category had at least two subcategories, most had more. These information categories were submitted to the CII research team in at the meeting in May.

The members of the CII research team members were asked to go to their organizations and validate the information that was presented as the information needs that might be addressed through wireless communication. They were asked to use their contacts in their companies or organizations to ensure that no important information needs were omitted. They were also asked to look at the content. The research team members

were asked to report any modifications that they came up with during the validation phase of the project.

The information needs subcategories were refined based on the information that was received back from the validation phase of the project. The research team's input and expertise were a very valuable aspect of the in articulating the information needs.

3.5 Conclusion

The CII research team played an active and important role in shaping this research. Their choice of the Lyondell - Citgo Refinery projects proved to be excellent for the purpose of data collection for the project. The data reconnaissance team gained information that was valuable to addressing the articulation of information needs as well showing some of the obstacles that wireless communication might have to overcome on the construction jobsite. There were some setbacks that the data collection team encountered during the data collection visit, with the questionnaires that were used and with the interviews. None of these setbacks proved to be major ones. The first iteration of the information needs articulation were reviewed and validated by the research team members who all have experience in the construction industry and are familiar with some of the communication challenges that are inherent with a construction project.

Chapter 4 Articulation of Information Needs

4.1 Information Needs Introduction

This chapter articulates the information needs at the jobsite which may be met by wireless communication technology. These needs are meant to represent typical examples; however, the list is not exhaustive.

Section 4.2 discusses each of the different types of wireless information formats that are being considered. For each format of wireless communication there is a generalized summary of how information is communicated. Additionally, some examples of what types and how much information can be communicated using the given format are included. Then, some advantages and disadvantages of each format are discussed.

Section 4.3 is the section that contains the actual information needs that have been compiled for this document. There are ten information need categories that are discussed. A table like the one shown in Figure 4.1 is used to discuss the general terms of the category and the details of the subcategories. An explanation of the headings in Figure 4.1 follows:

Information Subcategory	Explanation	Formats of Info. Transfer	Type	Delay (mins)	Importance	Simp. / Dup.	Data Rate (kbps)

Figure 4.1 Information Needs Charts Headings

- ◇ **Information Subcategory** - This identifies specific types of information that are needed at the jobsite.
- ◇ **Explanation** - This gives a brief definition of the what each information subcategory involves.

◇ **Formats of Information Transfer** - This column identifies the format in which the information could be transmitted wirelessly. There are four formats that will be considered. The first two, voice and video, are "live" transfers of information. This means that there is no latency in the data transfer. The third format is batched data. The fourth format is "live data."

◇ **Type** - This column further defines the format column. The different types for each format are as follows:

- Voice is defined by quality of service (QOS) as low, medium or high.
- Video is defined by quality of service (QOS) as low, medium or high.
- Batched Data Files are divided by file size as follows:
 1. Small - (< 5 kilobytes) - Included are e-mail, short text messages, and simple line drawings.
 2. Medium - (> 5 kilobytes, < 100 kilobytes) - Included are medium resolution graphics, large text documents and medium resolution digital pictures.
 3. Large - (> 100 kilobytes, < 1 Megabyte) - Included are high resolution graphics or pictures, moderate to high resolution video, CAD files and multimedia applications.

◇ **Delay** - The delay column defines how much of a delay in information transfer is allowable for a given format. The delay scale is as follows:

5 - Data can be transmitted within .01 minutes (No Latency)

4 - Data can be transmitted within .1 minutes (Minimal Latency)

3 - Data can be transmitted within 1 minute

2 - Data can be transmitted within 10 minutes

NF - Time is no factor

◇ **Importance** - This column gives a rating of how useful information transferred using a given format would be. This scale is based primarily on the information gathered during the LCR site visit.

5 - Very Important

4 - Somewhat Important

3 - As Important as Unimportant

2 - Not Very Important

1 - Unimportant

◇ **Simplex / Duplex** - This column defines whether one or two-way communication is necessary for a given application. If an application is simplex then the table will define whether the origin point of the information is the field or the trailer. (SF - Simplex originating in the field, ST Simplex originating in the trailer, D - Duplex).

◇ **Data Rate Required** - For each application, a required data rate will be determined. It will be based on the amount of information and the allowable delay. The following formula was used to determine data rates of batched files:

$$\text{Data Rate (kbps)} = \frac{(\text{Max. File Size (in Kilobytes)}) (1024 \text{ bytes / kilobyte}) (8 \text{ bits / byte}) (1 \text{ kilobit / 1000 bits})}{\text{Time (In Seconds)}}$$

Equation 4.1 Determining Data Rate Based on File Size

Example: If a file size of 5 kilobytes needs to be transmitted in 1 minute, then the data rate required would be:

$$\text{Data Rate} = \frac{(5 \text{ kilobytes}) (1024 \text{ bytes / kilobyte}) (8 \text{ bits / byte}) (1 \text{ kilobit / 1000 bits})}{60 \text{ seconds.}}$$

$$\text{Data Rate} = .683 \text{ kbps}$$

Figure 4.2 shows all of the data rates in kbps for the three different file sizes and for the four different delay ratings.

	Delay Rating			
File Size	< 10 mins.	< 1 min..	< .1 min.	<.01 min.
Small	.0683	.683	6.83	68.3
Medium	1.365	13.65	136.5	1365
Large	13.65	136.5	1365	13650

Figure 4.2 Data Rates (in kbps) Based on File Size and Delay Ratings as Defined

If the Delay Rating of “NF” was chosen for a batched file transfer, the Data Rate was set at not less than 1 kbps.

4.2 Different Formats of Wireless Communication to be Considered

The following are the different general formats of wireless communication that have been considered and will be discussed:

- Live Voice

- Live Video
- Batched Data Files
- Live Data Transfer (Future trends category only)

4.2.1 Live Voice Communication

Live voice communication is the ability for a party in the field to be able to talk with a party in the trailer, or somewhere else, without having to leave the field. Voice communication could be used to notify personnel in the trailer about any situation that may have arisen in the field. It could also be used as a conduit for information to flow between the trailer and the personnel in the field. As a means of information transfer it is limited to the same information that could be communicated verbally if the two parties were face to face. The walkie-talkie is an example of a voice only wireless communication device.

There are many advantages to live voice communication. First, a person in the field can get information from a person in the trailer in a very short amount of time. If the person in the field or trailer needed to communicate uncomplicated and short messages, voice communication lends itself well for that purpose.

Second, voice communication technology is usually easy to use and does not require much training. This means that a construction company that wanted to incorporate wireless voice communication probably would not have to invest a large amount of money to train its personnel in how to use the equipment.

Third, by using wireless voice communications, the personnel in the field are able to stay in the field and the personnel in the trailer are able to stay in the trailer. Without a wireless voice communication system a foreman from the field would have to go to, or send someone to, the trailer to get or deliver information. This inherently means that the

crew will lose some productivity because one of their crew members are gone or because the foreman is gone and the crew is unsupervised.

Finally, voice only communication has the potential to keep small problems from becoming large problems. If a problem arose in the field, a crew's foreman could let the trailer know that there is a problem and possibly get a solution right away. If not, at least the personnel in the trailer are aware that the problem exists and that the crew will need further instruction at a later time.

There are some drawbacks to voice only communication. As alluded to in the introduction, voice communication is effective for a small amount of uncomplicated information. "Historically, it has been claimed that man alone has the dubious distinction of being able to talk himself consistently into problems" [MEL79, p. 230]. By describing a problem situation verbally, the person describing the problem might make it harder to understand for the person he is describing it to. A person in the field might not be able to communicate complicated situations effectively through the use of a voice only communication system. This means that if a complicated situation arises, a person in the field would need to find alternate means of communicating the information to the personnel in the trailer. The same is true for the personnel in the trailer. In other words, a construction company that might invest in voice only communication still might find its foreman, or other personnel, needing to leave the field to communicate with the personnel in the trailer.

Another drawback is that voice communication is dependent on two parties having access to a communication device when one of the two parties needs to communicate. This means that if a party in the field needs to get into contact with a party in the trailer, the party in the trailer must be where he can receive the information. If the party in the trailer is away from his desk, the party in the field must either continue trying to establish communication or go to the trailer and locate the party that he needs to speak with.

4.2.2 Live Video Communication

Live video communication brings the jobsite to the trailer. The crew at the jobsite would need a video camera and an operator for the camera when using this method of communication. The crew in the field would be able to show the experts elsewhere the nature and scope of the problem or situation and how it relates to and effects the rest of the project. Once the signal is received at the trailer, it can be relayed to any location in the world using wireline communication technology or satellite-based technology.

The live video method of communication would be very effective if it were used in conjunction with a live voice method of communication. Voice communication would then allow the party in the field to explain the problem or situation while the party that is not in the field is viewing the video. Alternately, the off-site personnel, would be able to give directions to the camera operator.

The use of live video would allow a person not at the jobsite to see the situation in the field and get a better grasp of the situation. If live video were sent to design or engineering personnel off-site, they might be able to see conditions that could be missed using a voice only or text communication system. Based on the video, such off-site personnel might still decide they need to visit the site before making a recommendation.

Thus far a mobile camera that is operated by a person is the only type of video that has been considered. It should be mentioned that a camera could be mounted in a fixed position on the jobsite. Remote control of the camera could be established at the trailer or at an off-site location

Live video should only need to originate from the field. It should not be necessary for a video signal to be sent from the trailer or an off-site location to the field.

There are some disadvantages to using a live video communication system. First, the video recording equipment would need to be specially outfitted to be able to handle the harsh environments that are present at many construction sites.

Second, personnel not at the site must be careful not to become too dependent on live video as a representation of the complete story at the site. It might be easy for a person to think that the video is showing them everything that they need when it might not be. The personnel off-site can avoid this by actively communicating verbally with the personnel in the field, having them describe and clarify the video images.

Third, in spite of the investment that a company may make in the effort to being able to send live video, a crew may still stand idle while waiting for the proper personnel to be found to view the video.

Finally, a fixed position camera also has a few disadvantages associated with it. Since it is in a fixed position, the camera may not give the personnel away from the site the views of the site that need attention. Also, a fixed camera may need to be moved or adjusted throughout the life of a project as the topology of the site changes during construction. Additionally, a fixed camera may prove to be a distraction for workers. Studies have shown that workers may show a decrease in productivity when they feel that they are being watched. However, if the purpose of the cameras is fully explained to the workers they usually return to normal work patterns [OGL89]. This decrease in productivity might prove to be an unintended side effect of a fixed position camera.

4.2.3 Batched File Communication

The previous two sections addressed communication that was live in nature. This means that there was no latency between the time that information was sent from one source until the time that it was received at the other. This section will look at batched file communication.

Practically any computer application such as text, spreadsheets, databases, graphics, pictures, three dimensional CAD models, and movies, to name only a few, may be batched and sent via wireless means. The size of the file that is being sent and the

speed of the wireless communication technology being used are the determining factors in how long it will take to transfer a file. Section 4.1 defined file sizes. It should be understood that the divisions of small, medium and large were chosen in the context of wireless technology to be able to arrive at minimum required data rates for each of the types of transfer. Figure 4.3 is a log-log graph which examines how much time is required to transfer files of different sizes, given different data rates of wireless communication options under ideal conditions.

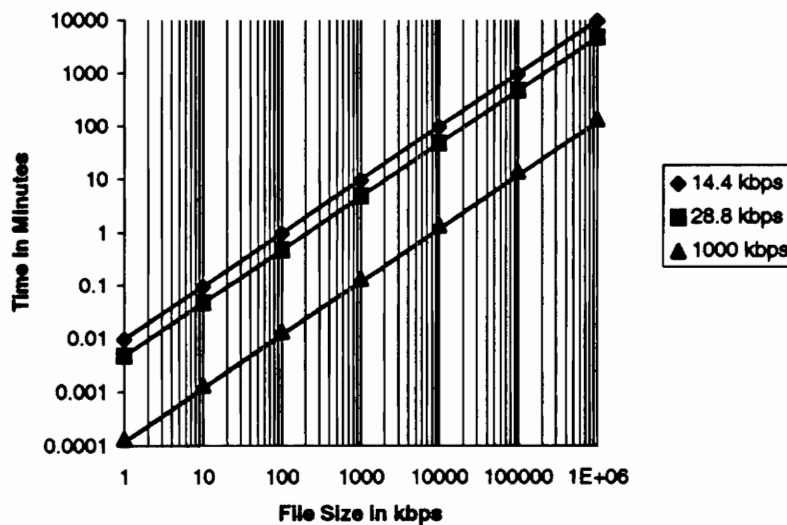


Figure 4.3 Comparison of Different Rates of Data Transfer (Using Equation 4.1)

4.2.3.1 Batched File Communication : Small Files (< 5 kb)

As defined in Section 4.1, small batched files will be those that are less than 5 kilobytes in size. These will mostly consist of text based messages, small amounts of database or spreadsheet information or simple line drawings. This type of communication is effective for communicating short messages, between the field and the trailer.

There are a number of information needs that can be met using small batched files. Using text based messages allows for a written record of a situation that has occurred in

the field to be sent to the appropriate parties in the trailer without the personnel in the field having to physically leave. If a situation occurs that is not urgent in nature, the personnel in the field can notify the personnel in the trailer without disturbing them from the work that they are doing. This type of communication would also allow for written instructions to be sent to the field from the trailer.

The first drawback to a batched file transfer is the latency that is involved. A person in the field might send some type of request that requires immediate action. The person in the trailer that needs to perform that action may not even find out that there is a written message from the field for some time. If the message is urgent, the person sending it should use voice communications to relay the message, or at least notify the person he is sending it to. However, the best use for any of the batched data file transfers is in situations that do not require the immediate attention of the person receiving it.

Another drawback is that the amount of information that can be communicated effectively using written means is limited. If there is a complex problem that has occurred in the field, it may take a person in the field more time to write and send a message describing the situation than it would for them to go to the trailer and communicate directly to the appropriate person there.

4.2.3.2 Batched File Communication : Medium Files (> 5 kb., < 100 kb.)

Medium batched files will be those that are between 5 and 100 kilobytes in size. These will mostly consist of longer text-based messages, databases, spreadsheets, moderate sized drawings, small three dimensional models, digital pictures, or short video files.

This type of file transfer allows for more flexibility in what type and how much information can be transferred as opposed to using small file transfers alone. For example, a foreman could take several photographs of an area in the field where a problem is

occurring using a digital camera. He could then send the pictures along with a text based message explaining the problem to personnel in the trailer. The photographs would give a better idea of the situation than just an explanation alone. Project drawing files and instructions might also be sent from the trailer to the field. Drawings and pictures are two of the main components of communication and understanding between different parties in the construction industry [OGL89]. This would allow the personnel in the field to have visual aids to go along with the instructions that they have been given. These are examples of just a few possible applications that are available using medium batched file transfers.

Most of the advantages that apply to batched transfer of small files also apply to medium files. Medium sized files just allow more information to be transferred than small files do.

As with small batched file transfers, there will be a latency that is involved; it will take time for the file to be transmitted. Then there is also the possibility that the person who is receiving it might not look at it for some time. If the information in the batched file is urgent, the person sending it should contact the person receiving it by voice to notify them that it has been sent. Still, medium file transfers are most effective for situation that do not require immediate action.

4.2.3.3 Batched File Communication : Large Files (> 100 kb., < 1 Mb.)

Large batched files will be those that are between 100 kilobytes and 1 megabyte in size. These will consist mostly of detailed drawings, moderate to large three dimensional CAD models, high resolution digital pictures, or moderate sized video files. This type of communication is effective for communicating large amounts of graphically oriented material. For example, a foreman may be having difficulty visualizing where a beam needs to be placed in a structure. The foreman might contact the trailer, using voice or a small

file transfer to request clarification. A person in the trailer would be able to send a three dimensional CAD model of the area in question to the foreman using a batched file transfer. This means that not only the amount of information that is transferred can be increased, but also the quality and clarity of the graphical applications can also be increased. The latency that is involved with small and medium files will still be present with the transfer of large files.

4.2.3.4 Batched File Communication : Access to the Contractor's Network

Another type of batched file transfer to consider is direct access to the contractor's computer network from the field. The contractor might want to give his foreman or field superintendents the capability to use some of the company's computer-based applications in the field without having to go to the trailer. For example, if the contractor used a scheduling software package to maintain his schedule, a foreman could check and manipulate the schedule without having to leave the field. By giving the field personnel direct access to the network, it would eliminate the need for the personnel in the trailer to be involved in the information transfer at all.

There are a number of information needs that can be met using this method. Most of these are of the record keeping or record updating nature. There are some important security considerations that need to be taken into account when a company expands the number of people who have access to its records.

One of the biggest advantages to giving a foreman or superintendent access to applications on the network is that it prevents a duplication of work. Without direct access, the foreman may have to fill out a report or submit a batched text file with the updates that he needs to make. These reports would then need to be entered into the contractor's network by another person in the trailer. This process could be automated by giving field personnel direct access to computer applications, some mistakes that have

occurred due to duplication might be avoided. It would also eliminate some work that had been previously handled by personnel in the trailer.

Another advantage is that in giving the field personnel direct access, they might be able to provide more up to date information. Without direct access, the information might become days old before it is recorded as computer files by the personnel in the trailer. By giving the personnel direct access, the field personnel can insure that the contractor's computer records are updated as soon as the information becomes available in the field.

Finally, if the personnel in the field need to look at a document or drawing, they would not need to use a person in the trailer to find the information and then download it to them, they could look up and find the information themselves. This again removes some work from the personnel in the trailer.

There are some disadvantages that need to be considered before giving field personnel access to the network. A contractor's management personnel should consider carefully which applications or systems they want to give the field personnel access to. A contractor might run into trouble if the field personnel were given full access to the contractor's payroll system, for example. Additionally, there might even be certain parts of an application that the contractor would not want field personnel to have access to. For example, the contractor might want to allow a foreman to update the schedule as an activity is completed. However, he would not want the foreman to be able to accidentally, or otherwise, change part of the original as-planned schedule.

4.2.3.5 Batched File Communication : Interactive Computer Application Communication (White Boarding)

There is a technique that is called "white boarding" that is used in hardwired communication environments. This technique allows two different parties at two different locations to view the same computer screen at the same time. Both parties have the capability to alter the screen or make notations or comments on it, for the other party to

see. This provides an interactive atmosphere to help facilitate better communication between the two parties. For example, a party in the field might need to communicate with an engineer located in the trailer or off-site. The person in the field could take a digital picture and send it to the engineer. The person in the field could indicate by highlighting on the picture where the problem is occurring to help the person off-site understand the situation better.

White boarding could work the opposite way as well. If a person away from the site needed to implement a change in the facility that is being constructed, they might put an engineer or architectural drawing on the screen and then show the modifications that need to be made. This would allow the person in the field to see where the changes are going to be incorporated.

There are a few distinct advantages that a white boarding technique has over other methods of wireless computer application communication. First, it allows for two parties to interact and 'discuss' a problem. Second, it allows both of these people, in the field and off-site, to easily establish a common baseline of understanding of the problem or situation that is being discussed. Finally, it allows for potential solutions to problems to be addressed at the time that a solution or problem is presented.

There are some disadvantages to a white boarding technique that should also be considered. First, and foremost the person off-site should not consider white boarding sessions as an alternative to visiting the site altogether.

4.2.4 Live Data Feeds

In the course of research for this project there were not many information needs that could be found that needed a live data feed. A live data feed is a continuous stream of information that would flow between a transmitter and a receiver. There were a couple of information needs that are discussed in Section 4.3.10 (Future Trends) that might require a live stream of data to be transmitted at the construction site in the future.

This type of transfer would require both locations be capable to send and receive data, albeit in small amounts with no or extremely minimal latency. This application was not explored in depth. Some examples of future applications that might require real time data transfer are:

1. Real - time positioning.
2. Real - time sensory data to be used in continuous diagnostics, monitoring and interpretation.

4.3 Information Needs Categories

There are ten broad categories of information needs. Each is discussed in detail in the following ten sections.

4.3.1 Information Category: Request for Information

This information category addresses the times that someone in the field might require more information from the contractor's personnel in the trailer, from an engineer or architect, from another owner's representative or from another source in order to complete the work that is at hand. There are countless types of 'Requests for Information' (RFI's). They have been divided into seven subcategories that address this type of jobsite information need.

Requests for Information and the timely response to them are an important aspect of any construction project. They are a conduit for information to flow between the field, the trailer and off-site locations. They are a means of solving problems that have been encountered in the field or to prevent future problems from occurring.

Ideally, if a field crew finds a problem that they cannot answer for themselves, they should be able to obtain a solution or the information necessary in a relatively quick

manner. If they can find the information they need quickly, it potentially prevents delays in the project and can help to keep things functioning smoothly at the site. Wireless communication techniques lend themselves well as a tool to aid in the reporting, processing, and answering of RFI's. Generally speaking, wireless communication will at a minimum increase the speed involved to process RFI's.

The seven subcategories for the RFI category are summarized in Table 4.1 and are explained next.

Table 4.1 Information Category: Requests for Information (RFIs)

Information Subcategory	Explanation	Formats of Info. Transfer	Type	Delay (mins)	Importance	Simp. / Dup.	Data Rate (in kbps)
1.) Design and Intent Clarification	Consultation with Engineers / Designers for questions regarding design and intent	Voice		<.01	5	D	8 - 32
		Video		<.01	1	SF	128 - 10,000
		Batched Data	Small	<1	4	D	0.68
2.) Subcontractor Information	Access to any information that the prime contractor has about any of their subcontractor's. Also, information about a sub-contractor's activities at any given time.	Voice		<.01	3	D	8 - 32
		Video		<.01	1	SF	128 - 10,000
		Batched Data	Small	<1	3	D	0.68
3.) Contract Specifications	Access to specifications or information regarding specifications.	Voice		<.01	5	D	8 - 32
		Video		<.01	1	SF	128 - 10,000
		Batched Data	Small	<1	3	D	0.68
4.) Contract Drawings	Access to contract or shop drawings and if necessary personnel that can answer questions regarding the drawings.	Voice		<.01	3	D	8 - 32
		Video		<.01	1	SF	128 - 10,000
		Batched Data	Small	<1	3	D	0.68
5.) Work Package Information	Access to work package information including scope of work, materials and equipment required, etc.	Voice		<.01	5	D	8 - 32
		Video		<.01	1	SF	128 - 10,000
		Batched Data	Small	<1	5	D	0.68
		Voice		<10	3	D	1.37
		Video		<10	1	D	>1
		Batched Data	Large	NF	1	D	>1

Table 4.1 Information Category: Requests for Information (RFIs)

Information Sub-category	Explanation	Formats of Info. Transfer	Type	Delay (mins)	Import.	Stimp. / Dup.	Data Rate (in kbps)
6.) Means and Methods Questions -	Should field personnel need to verify or consult about the planned means and methods.	Voice		<.01	5	D	8 - 32
		Video		<.01	1	SF	128 - 10,000
		Batched Data	Small	<1	5	D	0.68
7.) Implementation Problems	For consultation when field personnel discover that an item cannot be installed according to the owner's plans or contractor's methods.	Voice		<.01	5	D	8 - 32
		Video		<.01	1	SF	128 - 10,000
		Batched Data	Small	<1	4	D	0.68
			Medium	<1	3	D	13.65
			Large	<10	3	D	13.65
SUMMARY FOR CATEGORY							
			Average	Average (in Mins)	Average		Defining Value (kbps)
		Voice		<.01	4.43		8 - 32
		Video		<.01	1.00		128 - 10,000
		Batched Data	Small	<1	3.86		0.68
			Medium	<2.5	3.00		13.65
			Large	<10	2.29		13.65

Design and Intent Clarification: Sometimes in the course of construction, the personnel in the field cannot ascertain from the drawings, specifications or other documentation some aspects of the design being constructed or the intent of the designer. Often times participants in the construction industry (designers, engineers, architects and constructors) are not from the same company [BAK93]. Presently, the foreman or a crew member would need to leave the field and go to the trailer to request the information that is needed. Once there, he can look for clarification from drawings other than those in the field, look for clarification from engineering or other personnel in the trailer, or contact the owner's representative or the designer using conventional wired communication.

Subcontractor Information: On most construction projects, the prime contractor's personnel are required to work in close proximity to or in conjunction with personnel that work for a subcontractor. Often times, subcontractors perform as much or more of the actual work than the prime contractor's own personnel do [OBR91]. This means that in order for a project to be successful, the prime contractor's personnel must be able to interact with subcontractor personnel. In light of this interaction, it may become necessary for personnel in field to have access to information regarding the subcontractors that are on site. This information might include items like a subcontractor's schedule, work plan, responsibilities or even the name of a contact within the subcontracting company may be required.

Contract Specifications: Within any construction contract there are countless specifications or references to specifications that the contractor must adhere to. Specifications are part of the contract and they come from an organization external to the contractor [AND81]. Some specifications govern the method of construction (process specification), others govern the quality of the finished product (design specification). Since the quantity of specifications in a given contract might be voluminous it is

impossible for a foreman or a superintendent to be familiar with all of the specifications that are in a given contract.

In such a situation, the contractor's personnel in the field could ask a person in the trailer about the specification in question using live voice or by sending a text based message. The field personnel could explain the situation that needs a specification clarified. Then the trailer personnel could look up the specification in question and clarify by voice or if necessary, they could download a copy of the specification to the personnel in the field.

Contract Drawings: In many construction contracts there can be a large number of drawings to aid in the construction process. These drawings aid in the visualization of how the finished product is supposed to look. These drawings can take many formats, from a simple two dimensional sketch to a three dimensional CAD model. Drawings are often referred to during construction by foremen and crew members in the field.

Due to the large number of drawings that are in any contract, it can be difficult for the crew to have paper copies of all of the drawings in the field. On many construction projects, the management personnel try to determine which drawings are going to be needed by the crew and give them copies of those. A situation may arise where field personnel need to view a drawing that they do not have. In the current paradigm, a member of the crew must leave the field and return to the trailer to get a copy of the drawing that is required. This means that one member of the crew, usually the foreman, is lost while the drawing is being gotten from the trailer. Once there, the crew member must wait until the drawing that they are looking for is found.

Work Package Information: When most construction contractors start a project they break the work that will need to be performed into several smaller, more manageable parts. These parts are referred to as work packages. The number of work packages

varies depending on the size and complexity of the given project. One or more crews are generally assigned to complete each work package. Often times crews require information from the trailer regarding the scope or content of a work package. Also, when one work package is completed, the crew needs to get the next work package that they are going to be assigned to perform.

Wireless communication would allow the crews to get access to the work package information that they need from the trailer. There is the potential to increase a crew's productivity if they had access to the work package information they needed without having to leave the field.

Means and Methods Questions: When a construction company is planning how they are going to build a given project, they determine the means and methods that they are going to use. The means and methods that they choose will dictate how they will build the project, what equipment will be available for use, and other such defining parameters. Often times, in the course of construction a crew that is working needs to consult with an engineer or project management personnel about the means and methods that are to be employed.

A crew might encounter a situation in the field that was not accounted for during the means and methods planning stage. In a case like this the field personnel would want to discuss how to approach the difficulty with someone that is familiar with the logic that was involved in determining the means and methods. Wireless voice, video and batched file applications could be used as a means to transfer this type of information between the field and trailer.

Implementation Problems : In almost any job, things might not go according to plan. Certain work items may be difficult to install or implement according to the owner's plans or intent. It may also be difficult to implement an item in accordance with the

contractor's plan for construction. If such a case should arise in the field, it might be necessary for the field crew to get further instructions to resolve an implementation problem. It would be necessary to contact the engineer, architect or other owner's representative or the contractor's planning staff to find a way to resolve the implementation problem. Once a solution is found, it is necessary to communicate that solution back to the personnel in the field.

Summary of Information Needs : Referring to the summary section of Table 4.1, it can be seen that for all of the subcategories live voice was considered an important format of information transfer. Alternately, live video was not considered important. Small batched files were considered somewhat important and also required a low delay rating. The maximum data rate required for any of the batched transfers is 13.65 kbps.

4.3.2 Information Category: Materials Management

Most construction projects require that a large amount of materials be shipped to the construction site to be installed into the project. The coordination of ordering the required materials, receiving and storing them at the site, and bringing them to the area where they are to be installed in is a logistics challenge. Large projects can literally involve the installation of millions of different pieces of materials to produce the desired output. These materials can range in size from small screws to eight-hundred-ton prefabricated storage tanks. It is important for a construction company to be able to meet materials management challenges to insure that the proper materials are on site and ready for installation when they are needed.

The personnel in the field usually have a good grasp of what materials they need and when they will need them for installation. The field personnel are usually the first to know if the wrong piece of material has been sent or if a piece of material is missing. Yet,

for them to report such a problem, they need to leave their work and go to the job trailer or a materials yard. Communication between the parties at the construction site is an important link in effective materials management [STU95]. This is another area that may benefit greatly from the expanded use of wireless communication at the jobsite.

The five subcategories for the Materials Management category, are summarized in Table 4.2 and are explained next.

Access to Company's Material Management Information: To meet the challenge of managing large amounts of materials, many construction companies maintain large database programs to help in tracking materials from the time that they are ordered until the time that are actually installed in the facility that is being constructed [STU95]. Currently, for the most part, if a person in the field needs information from such a database, they must go to the trailer and use a computer there that has access to the database. The field crew will lose productivity while someone is sent to the trailer to retrieve information from a materials management database.

If a construction company uses such a database, they are making a monetary investment to develop and maintain it. It seems counterproductive that an important link in the tracking of materials, the field personnel, usually do not have access to such a system. The benefits of giving field personnel access to materials management database could be two-fold. First, the field personnel would benefit because they could have direct access to the materials database and not have to send someone to the trailer whenever a materials question arises. Second, the materials management division of the construction company could also benefit. If the field personnel had better access to a materials management system, they would be more likely to update it on a more regular basis. Thus, the records contained in the database would be more up to date and accurate.

Table 4.2 Information Category: Materials Management

Information Subcategory	Explanation	Formats of Info. Transfer	Type	Delay (mins)	Importance	Simp. / Dup.	Data Rate (in kbps)
1.) Access to Company's Material Management Information	To allow for access to a company's automated materials management information by field personnel.	Voice		<.01	4	D	8 - 32
		Video		<.01	1	SF	128 - 10,000
		Batched Data	Small	<1	5	D	0.68
2.) Material Location	To allow field personnel to find the location of any given piece of material that is required.	Voice	N/A	NF	1	D	> 1
		Video		<.01	4	D	8 - 32
		Batched Data	Small	<1	5	D	0.68
3.) Order Status	To allow personnel to find out what the status is of an item that has been ordered.	Voice	Medium	<1	3	D	13.65
		Video	Large	NF	1	D	> 1
		Batched Data	Small	<.01	5	D	8 - 32
4.) Request Materials to be Brought to the Site	When material is needed for installation, site personnel can order from the field.	Voice	Medium	<.01	1	SF	128 - 10,000
		Video	Large	<.01	1	D	0.68
		Batched Data	Small	<1	1	D	0.68
5.) Place Material Order to Offsite Location.	To order materials that need to arrive just in time, usually from local suppliers (e.g. concrete or asphalt). The information will be relayed through the trailer to the supplier.	Voice	Medium	<10	1	D	1.37
		Video	Large	NF	1	D	> 1
		Batched Data	Small	<.01	5	D	8 - 32
SUMMARY FOR CATEGORY		Voice	Large	<.01	1	D	128 - 10,000
		Video	Medium	<1	4	D	0.68
		Batched Data	Large	<1	1	D	13.65
				Average (in Mins)	Average	Defining Value (kbps)	
				<.01	4.60	8 - 32	
				<.01	1.00	128 - 10,000	
				<1	3.80	0.68	
				< 4.74	2.00	13.65	
				NF	1.00	> 1	

Material Location: Often times construction jobsites do not have much extra space for material storage where the work is being performed. When materials arrive at a construction site they are stored somewhere on the site, away from where the work is being performed. It can become difficult to keep track of where materials are located on the site or in the confines of the laydown yard. Often times, workers at the construction site have to spend time looking for materials that are needed but cannot be located.

Many companies already use control measures to keep track of materials once they arrive on site. The use of barcodes are one way to track materials at a construction site. Wireless communication can be used to determine the location of materials at the jobsite or in the laydown yard.

Material Order Status: The amount and variety of materials that are required at a construction site can be staggering. Many times a crew that is working in the field find themselves without the proper materials to complete the job at hand. It would be beneficial if a member of the crew were able to verify that the items that they are looking for have been received at the site before they start to look for them. It is a waste of time and very frustrating for field personnel to look for items that have not even been received at the site.

Request that Material be Brought to Jobsite: Materials that are used in construction are often stored away from the jobsite, in a laydown yard or another storage facility. When an item is needed for installation into the facility that is being constructed, a crew foreman, general foreman or a superintendent needs to arrange for that item to be transported to the jobsite from the storage area.

Place Material Order to Off-Site Location : There are some materials that are used in construction that need to arrive on site only when the site is ready for them to be installed. For example, concrete or asphalt cannot arrive too far in advance of the time that it needs to be placed. Therefore, it is sometimes necessary for an order of items such as these to be placed only when or shortly before the material is needed. This is assuming that there are previous arrangements in place with the suppliers of these materials to deliver when notified.

Summary of Information Needs: Referring to the summary section of Table 4.2, it can be seen that for most of the subcategories that live voice was considered an somewhat important format of information transfer. Alternately, live video was not considered unimportant . Small batched files were considered somewhat important and required a low delay rating. Medium and large files were considered to be not very important or unimportant. The maximum data rate required for any of the batched transfers is 13.65 kbps. However, this was for only one medium batched transfer in just one format in one information subcategory. If this one instance were put aside, the maximum data rate would only be 1.37 kbps to meet the information needs as stated.

4.3.3 Information Category: Equipment Management

In order to build most construction projects a contractor must use equipment. The type, size and amount of equipment that is needed will depend on the size and scope of the project that is being undertaken. The contractor will either own or rent the equipment. Whichever is the case, the contractor needs to maintain good records of how and how much the equipment is being used. Regardless of whether construction equipment is owned or rented, it accrues costs whether it is working or not [PEU96]. Therefore, a

contractor should want to take steps to maximize a piece of equipment's usage and minimize its down time.

In spite of the physical size of most construction equipment, it can be difficult to accurately track work that a given piece of equipment has performed on a given project. These records can be important for the current project at hand. Also, for many construction companies the record of how equipment performed on a previous job might be the basis of how equipment costs are figured into future project bids. Therefore, if accurate equipment records are not maintained, the company may run into trouble in the future because their bids are being based on faulty information. It is also important to remember that equipment represents a significant capital outlay for a company. This is another reason why a company may want to keep good records of how its equipment performs.

Wireless communication can aid in the record keeping and maintenance of equipment that is deployed in the field at a construction site. On smaller sites, wireless communication may not be as important to consider. However, on larger sites where a lot of equipment might be deployed, it has the potential to make equipment record keeping easier as well more accurate.

The two subcategories for the Equipment Management category are summarized in Table 4.3 and explained next.

Equipment Location: On larger construction sites, there may be many pieces of equipment that a contractor is using on the site. A given piece of equipment might be dedicated to one specific job or work area on the site or it might be used in several different areas even in the confines of a day. For the purpose of record keeping, it is beneficial for the contractor to keep an accurate record of what jobs a given piece of equipment performed and how long it took to perform them. This is important in the context of the current project because accurate records of expenses need to be maintained,

Table 4.3 Information Category: Equipment Management

Information Subcategory	Explanation	Formats of Info. Transfer	Type	Delay (mins)	Importance	Simp. / Dup.	Data Rate (in kbps)
1.) Equipment Location	To find the location of a given piece of equipment at any point in time.	Voice		<.01	5	D	8 - 32
		Video		<.01	1	SF	128 - 10,000
		Batched Data	Small	<1	4	D	0.68
2.) Fuel Monitoring and Refueling	To monitor fuel status and facilitate the routing of the fuel and oil trucks.		Medium	<10	3	D	1.37
			Large	NF	1	D	>1
3.) Fuel Monitoring and Refueling		Voice		<.01	5	D	8 - 32
		Video		<.01	1	SF	128 - 10,000
		Batched Data	Small	<1	4	D	0.68
4.) Fuel Monitoring and Refueling			Medium	<10	2	D	1.37
			Large	NF	1	D	>1
SUMMARY FOR CATEGORY							
		Voice		Average (in Mins)	Average		Defining Value (kbps)
		Video		<.01	5.00		8 - 32
		Batched Data	Small	<.01	1.00		128 - 10,000
			Medium	<1	4.00		0.68
			Large	<10	2.50		1.37
				NF	1.00		>1

to be compared with the budget. It is also important to keep these records as they can be one of the basis for productivity and cost estimates for bids on future projects.

If a piece of equipment is shared between several areas, it is important for personnel in each of these areas to know where it is at any given time. If a crew in one area is going to need the services of one piece of equipment that is located at another area, they would need to know where it is so that they could request it.

Equipment Fuel Monitoring and Refueling: If a piece of construction equipment runs out of fuel during the course of work then all work that the equipment is involved in must also stop until it can be refueled. This stoppage of work is a cause of lost productivity. This situation is easy to prevent from occurring if enough care is paid to the monitoring of a given piece equipment's fuel status. Live voice communication can be used by the equipment operators to contact the fuel truck. It is conceivable that fuel monitors could be installed on the equipment that send data directly to the fuel truck notifying it when the given piece of equipment was running low on fuel. If this type of technology became available, this subcategory would become a candidate for the "live data" format.

Summary of Information Needs: Referring to Table 4.3, it can be seen that for both of the subcategories live voice was considered a very important format of information transfer. Alternately, live video was considered unimportant. Small batched files were considered somewhat important and required a low delay rating. Medium and large files were considered to be not very important or unimportant. The maximum data rate required for any of the batched transfers is 1.37 kbps, which is relatively low.

4.3.4 Information Category: Cost Accounting

This information category addresses information needs relating to cost accounting and cost information that is needed by personnel in the field. There are some subcategories that are discussed here that could have also been discussed in other information categories. However, they were placed here because of their cost-related nature. This category is going to address information transfer needs that involve recording or accessing actual and / or proposed expenditures.

Accurate recording of expenditures in labor, material, and equipment are one way of tracking the progress of a project. If faulty, incomplete or inaccurate records are kept, the construction company may not know how well or poorly their crews are performing on a project. Cost accounting provides for both cost control and as a basis for estimation in future projects [CLO91]. Many contractors use historical cost data from previous projects to calculate costs and productivities that are used to bid future projects. If the records that a company uses are inaccurate then the company may have problems down the road with future projects.

Wireless communication techniques are well suited to ameliorate information flow in this category. Wireless communication could allow personnel in the field to gain access to budgets and other cost management information without having to leave the field. Additionally, field personnel could record costing information simultaneous to when the work is being performed, instead of at the end of a shift. This would allow the field personnel to record information while it is fresh in their minds.

The three subcategories for the Cost Management category are summarized in Table 4.4 and are explained below.

Budget: The budget that a contractor sets when constructing a facility is an important tool to measure performance. The budget usually becomes a baseline of reference for

Table 4.4 Information Category: Cost Management

Information Subcategory	Explanation	Formats of Info. Transfer	Type	Delay (mins)	Importance	Simp. / Dup.	Data Rate (in kbps)
1.) Budget	Access to estimated budget for time, materials and equipment.	Voice		<.01	3	D	8 - 32
		Video		<.01	1	SF	128 - 10,000
		Batched Data	Small	< 1	3	D	0.68
2.) Material Accounting and Cost Accounting	To record when, where and how much or how many of a given material is installed.	Voice		<.01	3	D	8 - 32
		Video		<.01	1	SF	128 - 10,000
		Batched Data	Small	< 1	4	D	0.68
			Medium	NF	1	D	> 1
			Large	NF	1	D	> 1
3.) Cost Accounting for Equipment	To record the cost code information for equipment that is being used.	Voice		<.01	2	D	8 - 32
		Video		<.01	1	SF	128 - 10,000
		Batched Data	Small	< 1	5	D	0.68
			Medium	NF	1	D	> 1
			Large	NF	1	D	> 1
SUMMARY FOR CATEGORY							
		Voice		Average (in Mins)	Average		Defining Value (kbps)
		Video		<.01	2.67		8 - 32
		Batched Data	Small	<.01	1.00		128 - 10,000
			Medium	< 1	4.00		0.68
			Large	NF	1.00		> 1
				NF	1.00		> 1

both monitoring the projects progress as well as a means of project control [HEN89]. The budget is usually broken down to match the work breakdown structure of the project where individual aspects of the project are assigned a projected cost. That cost is usually based on many factors, including the contractor's cost of the material, the amount of man hours involved and the equipment costs, to name few. Therefore, a contractor can look at how many man hours are spent to actually complete a segment of work and compare it to the amount of man hours budgeted for that piece of work and have some idea of how well he is performing in relation to the budget. The same could be done for equipment or materials costs.

There will be occasions where a party in the field may want to check the budget for a work item that may seem to be using an excess of man power, equipment or materials. Also, the situation could arise where a foreman in the field might want to have additional resources dedicated to a particular aspect of the project. He would want to check the budget for that particular work item before he requests the additional resources. There are several different formats of wireless technology he could use to accomplish this.

Material Cost Accounting: Section 4.3.2 discussed several aspects of material management that could be made easier at the jobsite using wireless communication. This subcategory deals with an aspect of materials management that was included in this category because it deals with the cost accounting of the materials. Materials represent a large expenditure that the contractor makes when constructing a project. "Cost control is a very difficult area of concern (in materials management) because there are many materials-related issues that relate to cost to control" [STU95, p. 174]. A portion of these cost are directly related to when and how the materials are installed.

At many construction sites, the contractor's field crew foreman keeps a written log of materials that are installed in a given day. At the end of the day, the log is submitted at the trailer and the materials that have been installed are recorded. Wireless

communication could eliminate the need for this type of written log and duplication of effort. Instead of having to wait for the end of the day to record materials that have been installed, the field personnel could send updates from the field throughout the day. Wireless communication could also be a good medium for inquiries about materials budget and costing information. Any queries that a person in the field needed to make, they could do from the field without having to go to the trailer.

Equipment Cost Accounting: Section 4.3.3 discussed some aspects of how wireless communication could be incorporated into the management of equipment at the construction site. However, the cost accounting of equipment is included in this category. The equipment at a construction site is either owned the contractor or leased by him, either way accurate records of the equipment's use should be maintained.

There are several reasons why a contractor might want to maintain records about equipment. First, many contractors use historical records to put together bids and budgets on future projects [DIA90]. Second, if the equipment is owned by the contractor, he wants to keep accurate records of how and how much a given machine has been used. Finally, if the contractor is working on a project that is cost reimbursable in nature, records must be kept so that contractor knows how much to bill the owner for equipment usage.

Summary of Information Needs: Referring to the summary section of Table 4.4, it can be seen that live voice was considered as important as unimportant as a format of information transfer. Live video was considered unimportant. Small batched files were considered a somewhat important format of information transfer and required a low delay rating. Medium and large files were considered to be unimportant. The maximum defined data rate for any of the batched transfers is .68 kbps for small batched files, which is low. For medium and large batched files, time is not a factor.

4.3.5 Information Category: Schedule and Means and Methods

Planning is considered to be one of the most important parts of a construction project [BAR84]. Planning includes creating a schedule for construction as well as deciding on the means and methods are going to be used. A schedule is an important aspect in planning a project. Not only is a good initial schedule important, but so is keeping the schedule updated and accurate. Often times the company's personnel in the field do not have easy access to the schedule or other planning information. Additionally, schedule updates by the field personnel might not be performed on a regular basis.

Wireless communication is a viable answer to solve some of the problems that occur because field personnel do not have timely access to planning information that they might require. Through the use of some the wireless communication techniques that have been discussed, personnel in the field could obtain the information that they require from the trailer. Alternately, it could provide an easier means for a foreman or superintendent to make updates involving the schedule or other planning aspects of a project.

The four subcategories for the Schedule and Means and Methods category are summarized in Table 4.5 and are explained below.

Schedule Updates: On a construction project, the schedule is the guideline to how that project is going to be built. However, there can be changes that need to be made to the schedule due to unforeseen conditions that might arise at the construction site, once the project is underway. This type of information should be recorded for future reference. Schedules need to be current to be effective tools and should be updated regularly, even on projects that are progressing well [CAL92].

It is important for a timely record to be kept of the changes in a project's schedule. There are two reasons for this. First, if one activity in a schedule is delayed for some

Table 4.5 Information Category: Schedule and Means and Methods

Information Subcategory	Explanation	Formats of Info. Transfer	Type	Delay (min)	Importance	Simp. / Dup.	Data Rate (in kbps)
1.) Schedule Updates	For field personnel to access schedules and update them based on the work that has been completed	Voice		<.01	4	D	8 - 32
		Video		<.01	1	SF	128 - 10,000
		Batched Data	Small	<.01	5	D	0.68
2.) Delay Recording	Recording delaying event information and the impact that it has on the project.	Voice		<.01	4	D	8 - 32
		Video		<.01	1	SF	128 - 10,000
		Batched Data	Small	<.01	5	D	0.68
3.) As Built Records of Construction	To record as built schedules.	Voice		<.01	4	D	8 - 32
		Video		<.01	1	SF	128 - 10,000
		Batched Data	Small	<.01	5	D	0.68
4.) Productivity Information	To record pertinent data that pertain to productivity and personnel management.	Voice		<.01	4	D	8 - 32
		Video		<.01	1	SF	128 - 10,000
		Batched Data	Small	<.01	5	D	0.68
SUMMARY FOR CATEGORY		Voice		<.01	4.00		8 - 32
		Video		<.01	1.00		128 - 10,000
		Batched Data	Small	<.01	5.00		0.68
			Medium	<10	1.25		13.65
			Large	NF	1.00		> 1

reason, it may have an effect on other activities' schedules or on the project as a whole. If the schedule is updated shortly after it changes, then the contractor can make adjustment to other activities schedules and possibly prevent further delay. Second, resources might need to be reassigned. If an activity is behind schedule project management might want to assign more resources to that activity in order to get it back on schedule. Alternately, if an activity is significantly ahead of schedule, the management might want to move some of the resources on that activity to another one.

Wireless communication techniques can be used to increase the timeliness and accuracy of schedule updates. Personnel in the field could send schedule updates throughout the day using wireless communication techniques to personnel in the trailer as activities are completed.

Delay Recording: In the course of construction there may be events that occur that cause an activity or the entire project to be delayed. Delays can be caused by the contractor, the owner or neither of the two parties. Failure to get materials or equipment on site are examples of delays caused by the contractor. Failure to provide access to the site or proper plans are examples of delays that might be caused by the owner. Adverse weather or a labor strike are examples of delays that are caused by neither party. The project's contract may contain liquidated damage clauses that require the contractor to pay monetary damages to the owner if the project's overall completion or a milestone is not finished on time. Therefore, it is important to know when and why a delay occurred as well as who is responsible for a delay. "Negotiations or settlements for delay related claims are often adversely effected by foremen's logs or diaries that are incomplete or inaccurate" [PAR93, p. 77].

Often times, a contract will exempt the contractor from delays caused by the owner or even by outside conditions. In other words, the contractor might need to prove that a delay or part of a delay was caused by the owner or was due to conditions beyond

either one's control. Many contractor's rely on daily logs that are kept by the foreman or superintendent as their record of delays. This means that the foreman or superintendent need to keep accurate records in their log books.

Wireless technology could be used to allow the field personnel to keep records of a delaying event at the same time as when the events happen. If a delay occurred in the field, a foreman would be able to report this event when it happens rather than waiting until the end of the shift or even the end of the week to make a record of them. If necessary, he could include a digital picture showing some aspect of the delaying event. This is an example of an application where the contractor could allow the foreman to have direct access to the network so that he could record the delay himself.

As Built Records of Construction: Many construction contracts require that the contractor keep accurate records of construction because there may be some variation from the as-planned schedule and as-built schedule. Many contractors also keep as-built schedule records so that they have a historical database to use as a basis for scheduling future projects.

These records can only be as good as the source that they are being recorded from. Crew foremen might wait until the end of a shift, the end of a week or even the end of a project to complete their as built schedules. This means that the data they record would not be as accurate as it would be if it could be recorded several times per shift or at the completion of any major task or schedule activity. "Sparse or faulty information makes development of as built schedules very difficult" [OBR91, p. 25.5].

A field crew foreman could use wireless communication to help in this area. The data that the as-built schedule would be based on would be more dependable than if the party in the field waited until the end of a shift to complete a schedule log.

Productivity Information: Some construction contractors base much of their planning of current projects on productivity information gathered from previous projects. Usually, productivities are calculated based on the total output of an activity divided by the number of hours expended on that activity. Usually there is no way to record some mitigating circumstance that might effect the productivity of an activity, other than examination of a foreman's log.

Wireless communications would allow a foreman in the field to record a circumstance that arises that might effect the productivity of certain aspect of the project.

Summary of Information Needs: Referring to the summary section of Table 4.5, it can be seen that live voice was only considered a somewhat important format of information transfer. Live video was considered unimportant. Small batched files were considered a very important type of batched file required a low delay rating. Medium and large files were considered to be unimportant. The maximum data rate required for any of the batched transfers is 13.65 kbps for a medium batched transfer that was rated as unimportant. The next highest data rate was .68 kbps.

4.3.6 Information Category: Jobsite Record Keeping

When a contractor has a crew in the field, there is a certain amount of “paperwork” that the foreman of the crew is expected to maintain on a daily basis. The foreman may be required to report items like the amount of time that his crew spent on certain activities, how long each member of his crew worked that day and other information. During the data reconnaissance visit to the Lyondell - Citgo Refinery project, one foreman that was interviewed stated that he spent up to two hours a day in the trailer completing paperwork. He said that this was time that his crew was working unsupervised.

Wireless communication techniques can be used to help ameliorate this information flow need. Use of wireless communication has the potential to allow the foreman to complete paperwork in an electronic format from the field. If the foreman were able to complete his paperwork throughout the day while work is going on, there might not be as much of it to do at the end of the shift. These records might be more accurate if the foreman completed them throughout the day. Under the current paradigm, the foreman has to wait until the end of the day to complete the paperwork and he is forced to try and remember events that have occurred as much as six to seven hours before.

The four subcategories for the Jobsite Record Keeping category are summarized in Table 4.6 and explained next.

Recording Time-Sheets: The foreman of a crew is often times expected to maintain record of how long each member of his crew works each day. Additionally, they are often required to maintain records of how long the crew spends working on a given activity. This can become a vast amount of information for the foreman to remember and record accurately at the end of the day. For example, the foreman might have eight workers on his crew that work on three different activities at different times throughout a ten hour work day. It would be difficult for anyone to try and remember which crew members worked on each activity and how long they spent on each. This type of record might be important because it can be the basis for the crew's pay. They also may be used as historical records to be used as the basis for bidding or planning future work. Finally, if the project is under a 'cost-plus' contract, time-sheet records are often times used as the basis of the owner's payments to the contractor.

Table 4.6 Information Category: Jobsite Record Keeping

Information Subcategory	Explanation	Formats of Info. Transfer	Type	Delay (mins)	Importance	Simp. / Dup.	Data Rate (in kbps)
1.) Recording Timesheets	Foremen would be able to perform daily timesheet recording from the field.	Voice		<.01	2	D	8 - 32
		Video		<.01	1	SF	128 - 10,000
		Batched Data	Small	<.1	5	D	0.68
2.) Progress Reporting	Field personnel would be able to submit progress reports from the field.	Medium		NF	1	D	>1
		Large		NF	1	D	>1
				<.01	2	D	8 - 32
3.) Exception / Incident Reporting	To be able to report work that was not installed according to plan.	Voice		<.01	1	SF	128 - 10,000
		Video		<.01	4	D	0.68
		Batched Data	Small	<.1	2	D	13.65
4.) Visitor's Log	To record visits to site by owner, engineer, safety inspector, contractors representative or other persons.	Large		NF	1	D	>1
				<.01	2	D	8 - 32
				<.01	1	SF	128 - 10,000
SUMMARY FOR CATEGORY		Voice		<.01	5	D	0.68
		Video		<.10	2	D	1.37
		Batched Data	Small	<.1	3	D	8 - 32
SUMMARY FOR CATEGORY		Medium		<.01	1	SF	128 - 10,000
		Large		<.1	4	D	0.68
				NF	1	D	>1
SUMMARY FOR CATEGORY				NF	1	D	>1
				Average (In Mins)	Average	Defining Value (kbps)	
				<.01	2.25	8 - 32	
SUMMARY FOR CATEGORY		Voice		<.01	1.00		128 - 10,000
		Video		<.01	4.33		0.68
		Batched Data	Small	<.1	1.67		13.65
SUMMARY FOR CATEGORY		Medium		<.55	1.00		>1
		Large		NF	1.00		

Wireless communication is a method of addressing the recording of time-sheet, in the field. Text-based batched files could be used to address this information need. The foreman in field would record the time-sheets for his crew throughout the day while work is going on. This information would be sent to the trailer and recorded in a time-keeping computer program. This is another example of a situation where the foreman could be given direct access to the contractor's network. He would be update his crew members' time-sheets without having to rely on anyone in the trailer complete the information.

Progress Reporting: One way that a contractor can tell how well or how poorly he is performing on a project is to keep track of and to measure his progress. His foremen or superintendents are usually responsible for making progress reports on a daily or weekly basis. As with time-sheet recording, the person that needs to submit a progress report may have to do it several hours or days after the events have taken place. This means that an activity might have been completed on Monday, but by the time the foreman submits a progress report, he thinks that the activity was completed on Tuesday and records it as such. There may be some loss in the accuracy of progress information that is recorded. In many cases progress reports are the basis for payment from the owner. They are also be used by the contractor to bid or to schedule future projects.

Wireless communications would allow a foreman to update his progress with the trailer as activities are completed in the field. The field personnel might also be given the capability to send batched files that contain a message stating that certain activities are complete. The foreman could send digital pictures of an activity when it is complete, if the company had a need for a visual record.

Exception Reporting: Often times, conditions in the field require that minor variations be made in the original plans when an item is being installed. Usually this type variation is very minor in nature and inconsequential to the facility being constructed to be

performed without having to get permission from the owner. The foreman of the crew that made the minor change needs to report the change to the personnel in the trailer who can then forward it on to the appropriate owner's representative.

The contractor could use wireless communication to expedite the sending of these reports to the owner's representative. If necessary, the foreman could send digital pictures of the change and pictures to help explain the change was necessary.

Visitor's Log: A crew working in the field might be visited by personnel from within the contractor's organization or by personnel in the owner's organization. It might be necessary for a foreman or superintendent of the crew to keep a record of who has visited the site and any instructions that might have been given.

Voice only wireless communication would allow the foreman to contact the trailer when visitors arrive at the site. The foreman could let the personnel in the trailer know who was visiting the site and what they did while they were there. The foreman could also send a text file that contains the important information about the visit.

Summary of Information Needs: Referring to the summary section of Table 4.6, it can be seen that for all of the subcategories live voice was considered a not very important format of information transfer. Live video was considered an unimportant format. Small batched files were considered to be a somewhat important type of batched file and required a low delay rating. Medium and large files were not considered to be unimportant. The maximum data rate required for any of the batched transfers is 13.65 kbps for a medium batched transfer that was rated as unimportant. The next highest data rate was .68 kbps.

4.3.7 Information Category: Submittals

Many construction contracts require the contractor to make submissions to the owner, or one of his representatives, that show how work is going to be performed or some other aspect of the construction process. Often times construction or engineering crews are required to perform some task in the field that needs to be submitted for the record or for approval by the owner or one of his representatives. The contractor's personnel usually makes the necessary observations from the field and then submits them to the owner from the trailer.

If the contractor had access to wireless communication techniques, the personnel in his organization that needed to make submittals would be able to do so from the field. Personnel could make observations or perform tests in the field and be able to relay the results to the trailer where they could be sent on to the owner's for approval.

The two subcategories for the submittals category are summarized in Table 4.7 and are explained next.

Test Results: A construction contract may require the contractor to perform tests on site during construction. These tests can include concrete slump testing, geotechnical testing, electrical testing and mechanical testing to name only a few. The contract may stipulate that the results of the tests need to be submitted to the engineer or another of the owner's representative. The contractor's personnel that perform these test might wait until several of the tests are performed in the field before returning to the trailer to submit the results to the owner's designee.

Wireless communication techniques could be used to send test results from the field to the trailer. The contractor could give the party that is performing the test the capability to transmit batched files. When a test is finished, its results can be sent in a text format to the trailer and or directly to the owner's designee. If a digital camera were

Table 4.7 Information Category: Submittals

Information Subcategory	Explanation	Formats of Info. Transfer	Type	Delay (mins)	Importance	Simp. / Dup.	Data Rate (in kbps)
1.) Test Results	To submit results of owner's, engineer's or contractor's tests on site.	Voice		<.01	3	D	8 - 32
		Video		<.01	1	SF	128 - 10,000
		Batched Data	Small	<1	4	D	0.68
2.) Revisions to Previous Submittals	To send any changes to any previous submittals that might have been changed in the field during progress.	Medium	Medium	<10	3	D	1.37
		Large	Large	NF	1	D	> 1
				<.01	3	D	8 - 32
		Video		<.01	1	SF	128 - 10,000
		Batched Data	Small	<1	5	D	0.68
			Medium	<10	4	D	1.37
			Large	<10	2	D	13.65
SUMMARY FOR CATEGORY							
				Average (in Mins)	Average		Defining Value (kbps)
		Voice		<.01	3.00		8 - 32
		Video		<.01	1.00		128 - 10,000
		Batched Data	Small	<1	4.50		0.68
			Medium	<10	3.50		1.37
			Large	<10	1.50		13.65

available, the party in the field could take pictures of the test and its results and send them with the written results.

Revisions to Previous Submittals: Contractors are often required to make many submittals to the owner or one of his representatives before work starts on a project. During the course of working on the project it might become necessary to make revisions or alterations to the original submittals that were sent to the owner for approval. There are many situations that might cause these changes in the original submittals to be necessary. For instance, the contractor might encounter site conditions that are different when he starts work. A supplier might not be able to provide an item that had been incorporated into a submittal. There are numerous other possible reasons why a contractor might need to revise a submittal.

Wireless communication has the potential to speed up the process of submitting a revision to a previous submittal. If the contractor's person in the field had access to batched file transfer, they could send the information necessary to a revision to the trailer. The party in the field could attach digital photographs of the effected area to help explain the situation to people not at the site.

Summary of Information Needs : Referring to the summary section of Table 4.7, it can be seen that the live voice format was considered to be as important as unimportant. Small batched files were considered to be somewhat important to very important, and it required a low delay rating. Medium files were considered to be somewhat important. Large files were not considered to be important to meet any of these information needs. The maximum data rate required for any of the batched transfers is 13.65 kbps for one a large file that was considered not very important. The next highest data rate that was required was 1.37 kbps.

4.3.8 Information Category: Safety

It is one of the primary goals of most contractors to maintain a safe jobsite that is free of accidents. Some contractors expend much effort to emphasize safety to their personnel that are working at a site. A safe project can only be achieved through education, vigilance, and the cooperation of all parties involved during the construction process [HEN89]. However, despite a company's best efforts at prevention, accidents can and do still occur at construction sites. Contractors should continue to stress safety measures and policies at jobsites, but should also be prepared to deal with accidents when they occur.

Wireless communications have the potential to help with both the prevention of accidents as well as dealing with them when they occur. Wireless communications can be used to train personnel in emergency procedures and in new safety procedures. They can also be used to help prevent accidents from happening by allowing personnel in the field to report situations or practices that may not meet the safety standards of the company. Finally, they can be used to report accidents and coordinate emergency crews response to the accidents.

The three subcategories for the safety category are summarized in Table 4.8 and explained below.

Safety Accident Reporting: In the event that an accident should occur a company should be prepared to deal with it in a manner to minimize injury, loss of life or loss of property. The contractor should have a standing plan of action for dealing with safety accidents of all type and sizes.

Wireless communication can play a role in a company's accident management plan. A company can insure that all personnel on the site have relatively quick access to wireless voice communication so that an accident can be reported to the trailer in the quickest

Table 4.8 Information Category: Safety

Information Subcategory	Explanation	Formats of Info. Transfer	Type	Delay (mins)	Importance	Simp. / Dup.	Data Rate (in kbps)
1.) Safety Accident Reporting	To allow any crew member to report an accident as soon after it occurs as possible. Also, to aid in coordinating emergency team response.	Voice		<.01	5	D	8 - 32
		Video		<.01	1	SF	128 - 10,000
		Batched Data	Small	<.1	2	D	6.82
2.) Report Possible Safety Violations	To allow any personnel to report the possibility of safety violations in the field.	Voice		<.01	5	D	8 - 32
		Video		<.01	1	SF	128 - 10,000
		Batched Data	Small	<.1	2	D	6.82
3.) Access to Company Safety Policies and Procedures	To allow personnel in the field to have access to company and site specific safety policies and procedures.	Voice		<.01	3	D	8 - 32
		Video		<.01	1	SF	128 - 10,000
		Batched Data	Small	<.1	3	D	0.68
SUMMARY FOR CATEGORY		Voice		<.1	3	D	13.65
		Video		NF	1	D	>1
		Batched Data	Small	>.1	2.33		
			Medium	>1	2.33		
			Large	NF	1.00		
				Average (In Mins)	Average		Defining Value (kbps)
				<.01	4.33		8 - 32
				<.01	1.00		128 - 10,000
				<0.4	2.33		6.82
				>1	2.33		13.65
				NF	1.00		>1

manner possible. If the personnel in the field has access to live video and a severe accident were to occur, rescue and emergency response efforts might be better coordinated since the personnel away from the accident would be able to see the nature and extent of the accident.

Report Possible Safety Violations: Many contractors encourage their personnel to report practices or situations that are not safe. This alerts the company's management or safety personnel so that the situation or practice can be investigated and changed if need be. Even if a company does not have a policy for their employees to follow to report potentially dangerous situations they probably still want to know about them. It is easier to correct a dangerous situation than it is to deal with the effects of an accident.

Voice only wireless communications could be used by personnel in the field to report situations that have the potential to turn into an accident. A batched text file transfer should also be considered as a method to report possible safety violations.

Access to Company's Safety Policies and Procedures: Many construction companies have set procedures and policies that deal with the safest way to perform certain activities. Safety manuals can be lengthy and may not be readily available to personnel in the field. If someone in the field had easy access to their company's safety literature, it could make for a safer workplace.

There are some ways that wireless communication can be useful in this area. One possibility is for the company to put their safety manuals on-line so that they can be accessed from the field. This would allow field personnel to directly consult the necessary sections from a safety manual without having to leave the field.

Summary of Information Needs : Referring to the summary section of Table 4.8, it can be seen that for all of the subcategories live voice was considered a very

important format of information transfer. Live video was not considered important in any of the information needs. Small and medium batched files were considered not very important but required a fairly fast data rate. This is because if a crisis situation occurred at the jobsite it would be necessary to be able to coordinate with the trailer without delay. Large files were considered to be unimportant. The maximum data rate required for any of the batched transfers is 13.65 kbps for the medium batched transfers and were rated as unimportant. The next highest data rate was 6.83 kbps.

4.3.9 Information Category: Quality Control / Quality Assurance (QC / QA)

In most construction contracts, the contractor is responsible for not only the construction of a facility, but also the quality of the construction. The owner can state a certain level of performance that the facility or a part of the facility needs to meet. The owner can appoint an outside party to perform any quality checks, or he might allow the contractor to perform and submit the quality checks himself. Either way, the contractor may be required to maintain detailed records for quality control. Alternately, the contractor himself may have strict internal quality assurance procedures and would still have the need to maintain accurate records for construction purposes. Defects or failures in a constructed facility or even minor defects that result in rework can mean large additional costs to the contractor [HEN89].

Several different forms of wireless communication can be used to get quality control information to and from the field. There is also the potential that at some point in the future quality control inspections might be able to be performed by an inspector not at the site. Wireless communications have the potential to prevent work in the field from stopping while waiting for an inspector to perform a quality check at the site.

The three subcategories for the quality control / quality assurance category are summarized in Table 4.9.

Initiate Inspection Procedures: Once an activity is completed that requires a quality inspection there can be a delay between the time that task is complete and when the inspection starts and is completed. It might be necessary to send a crew member to the trailer to inform the inspection personnel that an inspection is required. There may be some down time for the crew, especially if the start of their next task is dependent on the inspection of the previous task.

Voice only wireless communications could be used to notify the personnel in the trailer that an inspection is needed without requiring a crew member to leave the field. Since this information need might not be very time dependent, the foreman of a crew could then send a batched file to the trailer stating what inspection is needed and when the work was completed or will be completed. The personnel in the field could also be equipped to send digital pictures of the area that needs to be inspected, if the crew has the capability to transfer medium files.

Report QC / QA Problems: On a construction site there are occasions when a person in the field notices that something was not built or installed to the company's or owner's quality standards. The construction company's management should want to be informed of work that does not meet standards, so that corrective measures can be made to rectify the problem. If someone on site notices something that they think might be substandard, but has to wait several hours before they can report it, they may forget it.

Wireless communication techniques have the potential to make the reporting of quality problems from the field easier. Voice communication is the best solution for this problem. If someone in the field spots a problem, they could communicate the problem to the trailer as soon as they notice it, without having to leave the field. A company could

Table 4.9 Information Category: Quality Control / Quality Assurance (QC/QA)

Information Subcategory	Explanation	Formats of Info. Transfer	Type	Delay (mins)	Importance	Simp. / Dup.	Data Rate (in kbps)
1.) Initiate Inspection Procedures	To allow personnel in the field to notify company or owner's inspection personnel when a work package or area is ready for inspection.	Voice		<.01	5	D	8 - 32
		Video		<.01	1	SF	128 - 10,000
		Batched Data	Small	< 1	2	D	0.68
2.) Report QC / QA Problems	To allow field personnel to report work that might meet quality standards.	Medium	Medium	<10	2	D	13.65
		Large	Large	NF	1	D	> 1
				<.01	5	D	8 - 32
3.) Reporting QC / QA Results	To allow the company's inspection personnel to submit inspection results for from the field.	Video		<.01	1	SF	128 - 10,000
		Batched Data	Small	< 1	5	D	0.68
			Medium	<10	4	D	13.65
			Large	NF	1	D	> 1
SUMMARY FOR CATEGORY							
				Average (in Mins)	Average		Defining Value (kbps)
		Voice		<.01	4.33		8 - 32
		Video		<.01	1.00		128 - 10,000
		Batched Data	Small	< 1	3.33		0.68
			Medium	<10	2.67		13.65
			Large	NF	1.00		> 1

give the personnel in the field the ability to send a digital photograph of the area that they feel has a quality problem to the document in question.

Reporting QC / QA Inspection Results: The first section of this information category discussed the need for quality inspections as well as the need to have an easy way of initiating them. Once a quality inspection has been performed, the inspector needs to report his results to the contractor's personnel, as well as to the owner. Sometimes further work on the project may be delayed until something passes a quality inspection. This means that a crew and equipment may stand idle until the inspection is completed.

The results of a quality inspection could easily be relayed using wireless means. Once an inspector approves of a piece of work, he could use several different means of wireless communication to relay the results of an inspection to the personnel not at the jobsite. If the inspector was going to be in the field for a long period of time, he could record the result in a batched file and transmit it to the trailer. If this were the case, then the inspector could also use a digital camera to pictures of the inspected work and send them to the off-site personnel wirelessly.

Summary of Information Needs: Referring to the summary section of Table 4.9, it can be seen that live voice was considered a very important format of information transfer. Live video was considered unimportant for all of the information needs. Small batched files were considered as important as unimportant. Medium files was considered as not very important and large were considered unimportant. The medium batched files required the maximum data rate of 13.65 kbps.

4.3.10 Information Category : Future Trends

The construction industry is constantly changing. It is difficult to predict developments that may change the way that construction is performed. This final information needs category attempts to look at two trends that may become important aspects of the construction industry in the future.

As mentioned in Section 4.2.4, there might be a need to establish a live flow of data on the construction site at some point in the future. This type of data flow will need to be achieved using wireless communication techniques. This type of communication is one of the keys to getting more automated equipment into the construction industry.

The two subcategories for the future trends category are summarized in Table 4.10. This table does not include the batched file format. The future trends applications that are being considered do not have a need for batched files, therefore, they were not investigated.

Positioning Data: The first future trend that is going to be explored is the transfer of positioning data. In the very near future, it will be possible to have sensors that collect real-time positioning data throughout a construction site. Positioning information could be recorded continuously by positioning devices throughout the site. This data would allow an accurate model of the site to be maintained. For example, if a positioning system were in place on the site and grading operation was underway, as the grader makes a pass, the positioning system would update the model of the site to reflect the change in grade.

Position recording devices could also be incorporated into construction equipment that is on the site. Then these positioning devices could be made to send signals that had the x, y, and z coordinates for a given part of the piece of equipment in question. If this type of positioning device were incorporate into the boom of a robotic crane, then the positioning device would send information to the crane's operator about the booms exact

Table 4.10 Information Category: Future Trends

Information Instance	Explanation	Formats of Info. Transfer	Delay (mins)	Importance	Simp. / Dup.	Data Rate (in kbps)
1.) Positioning Data	To allow rapid updates of records of construction to be made concurrent with the work in progress. Also to allow for spatial positioning.	Voice	<.01	5	D	8 - 32
		Video	<.01	2	SF	128 - 10,000
		*Live Data	<.01	5	D	>14.4
2.) Sensor and Control Data	To all readings to be made from sensors that are incorporated into equipment or personnel. Also to allow electronic commands to be sent to the equipment from a remote location.	Voice	<.01	5	D	8 - 32
		Video	<.01	1	SF	128 - 10,000
		*Live Data	<.01	5	D	>14.4
SUMMARY FOR CATEGORY						
* Added for this information category only		Voice	Average (in Mins)	Average	Defining Value (kbps)	
		Video	<.01	5.00	8 - 32	
		*Live Data	<.01	1.50	128 - 10,000	
			<.01	5.00	>14.4	

position at any point in time. If this information could be used in conjunction with a real-time model of the jobsite then a computer model could be used to optimize lifts and swings of the boom.

Sensor Data: The other trend that will be explored is the use of sensors on different object in the construction site. One type of sensor that may become a part of a construction site is a control sensor. Control sensors can be installed on automated equipment to receive signals from a the person that is controlling the equipment. This type of sensor could be used in conjunction with positioning devices to give the operator accurate information about various systems on the machine. For example, if a person was controlling an automated excavator, the sensor might let him know the positions of the stick, bucket, boom, and tracks. Then the person controlling the excavator could send signals to it to perform the next task. The possibilities for automation at the construction site are still not fully explored. The advent of wireless technology may make the proliferation of automated equipment to the construction site easier.

Another type of sensor that might finds its way on to the construction soon is an RF (radio frequency) identification tag. This refers to a tag that could be attached every piece of material that is received at the site. This would emit a signal that identifies the piece of material. If a crew in the field needed a certain piece of material, the workers in the laydown yard would enter the information about the material into an RF receiver. The RF receiver would be programmed to show the location of the given RF tag in the laydown yard. This would make location of the material easier than the current method of searching.

Summary of Information Needs : The importance ratings for this category were not taken from the LCR study. They were assigned based on how important the given format would be to make the technology work effectively at a construction site assuming

that the technology to was available. By referring to Table 4.10 it can be seen that voice transfers were still considered important. Live video was not considered important, although as technology in these areas progress, it may become more important. Live data applications were considered important and require a high data rate. For some applications, the live data stream could need to be updated up to 100 times per second.

4.4 Conclusion

This chapter discussed information needs at the jobsite that might be addressed by wireless communication. Further, it discussed in broad terms different types of wireless communication that might be used to address these information needs. As stated in the introduction of this chapter, the information needs that are discussed here are by no means meant to represent all of the possible information needs that might arise at any construction site. They are meant to show ways that wireless technology might be incorporated into the construction jobsite.

The construction industry is generally more adverse to change than most industries are. In other words, change in the industry usually does not occur overnight. However, the wireless technology industry is very fluid and breakthroughs can happen rapidly. Therefore, although the information needs of the construction industry may not change dramatically over time, the means that are available to meet those needs will change at a rapid pace. The information contained in this chapter can be used as a guideline to incorporating future wireless technology into the industry.

The most commonly regarded format of information transfer is live voice. This format of information transfer is already commonly used in the construction industry, in the form of walkie-talkies. Small and medium batched files were also regarded favorably. Some the applications of these two formats will make a foreman's daily workload lighter. Video and large batched files were not regarded well. After the other formats of wireless

information transfer are incorporated onto the construction jobsite, people there might become more amicable to these two formats.

Chapter 5 Framework for Technology Assessment

5.1 Information Needs Introduction

This chapter will examine how to evaluate the applicability of wireless technology that is commercially available based on the information needs that a company may have. The first half of this chapter will do two things. First, it will summarize some of the information needs that were addressed in Chapter 4. Second, it will examine how to determine if a given type of wireless technology will or will not be able to handle the information needs that a company has. The second half of the chapter will present two hypothetical examples. The first will show how to use the tools that have been presented in this document to determine if a given wireless technology should even be considered as a viable way of meeting the information needs that a company has. The second will show how a construction company can customize information needs to meet their own priorities.

If a company chooses to incorporate wireless technology on to their jobsites they will be making an investment in wireless hardware. The information presented here is not meant to be a fixed method for the selection of wireless technology. It is instead presented to show some of the nuances that need to be considered when a company is investing in wireless so that they avoid investing in technology that will not perform as expected.

5.2 Framework for Wireless Technology Assessment

The next few sections will discuss what information is needed in order to assess the applicability of wireless technologies. This constitutes the basic framework for

assessing wireless technology to find solutions that might meet a company's information needs.

5.2.1 Information Needs Assessment and Summary

Before a construction company starts consider the purchase wireless technology, it should identify what information needs they hope to meet. Any company should want to make sure that they at least have a need for any technology before they invest in it. A company will also want to insure that it purchases equipment that is capable of meeting their desired needs. Therefore, it needs to have a good definition of what their needs are. If a company invests the time necessary to articulate what type, format and quantity of information they hope to send wirelessly, then it will be more likely to identify the wireless technology that is well suited to meet their needs.

Chapter 4 of this document identified numerous information needs that might be met on a construction jobsite through the use of wireless technology. Table 5.1 summarizes the information needs for nine of the ten categories that were discussed. (The Future Trends Category was not included because it did not have any batched applications included.) This shows the maximum data rates that are required for each size of batched file transfer. The data rates required for live voice and live video are listed once, in Table 5.2, since these data rates are for a given quality of service, they are the same for all nine categories.

This table is a tool that companies can use to identify the data rates that they require. The information contained in this table was arrived at through the input of people in the construction industry. It is not presented with the intention that it is a representation of the information needs of every contractor or every jobsite. It is instead presented to show many information needs that could possibly be met using wireless technology. The format it is presented in can be used by a company to help assess their own information

needs. Two examples of how a company could use these tools to articulate their own information needs is given in Sections 5.3 and 5.4.

Table 5.1 Summary of Data Rates Required for Information Needs Articulated in
Chapter 4

Information Category	Formats of Info. Transfer	Type (file size)	Data Rate (kbps)
1.) Requests for Information	Batched Files	Small	.68
		Medium	13.65
		Large	13.65
2.) Materials Management	Batched Files	Small	.68
		Medium	13.65
		Large	> 1
3.) Equipment Management	Batched Files	Small	.68
		Medium	13.65
		Large	> 1
4.) Cost Management	Batched Files	Small	.68
		Medium	> 1
		Large	> 1
5.) Schedule and Means Methods	Batched Files	Small	1.37
		Medium	13.65
		Large	> 1
6.) Jobsite Record Keeping	Batched Files	Small	.68
		Medium	13.65
		Large	> 1
7.) Submittals	Batched Files	Small	.68
		Medium	1.37
		Large	13.65
8.) Safety	Batched Files	Small	6.82
		Medium	13.65
		Large	> 1
9.) QC / QA	Batched Files	Small	.68
		Medium	13.65
		Large	> 1

Table 5.2 Summary of Data Rates for Required for Different Level of Quality of Service

Information Category	Formats of Info. Transfer	Type (QOS)	Data Rate (kbps)
Summary for All Categories Live Voice and Video	Voice	Low	8
		Medium	16
		High	32
	Video	Low	128
		Medium	1,500
		High	10,000

5.2.2 Restriction of Wireless Technology Based on Data Rate Requirements

This section will show how to eliminate different types of wireless communication technology from consideration based on the data rates that have been identified for the information needs. This section is not intended to validate the use of any particular wireless technology but to show which ones will not work based on data rate requirements alone.

Table 5.3 is presented as a tool for eliminating different types of wireless communication from consideration. The left most columns of this table identify different formats of information transfer. For voice and video, the three levels of quality of service are identified, and for batched files three different ranges of data rates are identified. The top row identifies several categories of wireless technology that are currently available. Inside the table, a notation of 'N/A' means that currently the given technology will not support the data rates required for the given application. A check mark indicates that there is technology available that will support the data rate required for the given application. A check mark is not an endorsement of the technology for that application. There are other technical issues that must be investigated before choosing a particular wireless technology.

For example, if one were to examine the CDPD column in Table 5.3, one can see that CDPD could support low and medium quality live voice communications, but not high quality. Looking further down the column, it can be seen that CDPD cannot support any live video applications. For batched data, the table shows that CDPD can support low data rates. By looking at footnote 3, it can be seen that CDPD can only support medium data rates to the middle of the defined data rate range. Finally, it can be seen that CDPD cannot support high data rates.

Continuing with the example, if one a construction company determined that it wanted to do wireless batched file communication, and needed their wireless system to be capable to achieve a data rate of 12 kbps. The data rate that is required falls into the medium batched file category. Starting at the left side one can see that the Circuit Switched Cellular Modem format will support this format of wireless transfer. Moving to the right of the table, it can be seen that the Packet Switched SMR format will only support data rates to the middle of the defined range. Therefore, on this basis, they should not be considered as an option. The same is true for CDPD. Wireless LAN will support the required data rate. Paging and Satellite will not support the required data rate.

Table 5.3 Framework for Elimination of Wireless Communication from Consideration

	Required Data Rate (kbps)	Circuit Switched Cellular Modem	Packet Switched SMR	CDPD	Wireless LAN	Paging	Satellite
VOICE							
	QOS						
	LOW	✓ ¹	✓ ¹	✓ ¹	✓ ²	N/A	✓
	MEDIUM	✓ ¹	✓ ¹	✓ ¹	✓ ²	N/A	N/A
	HIGH	N/A	N/A	N/A	✓ ²	N/A	N/A
VIDEO							
	QOS						
	LOW	N/A	N/A	N/A	✓ ²	N/A	N/A
	MEDIUM	N/A	N/A	N/A	N/A	N/A	N/A
	HIGH	N/A	N/A	N/A	N/A	N/A	N/A
BATCHED DATA RATE							
	LOW	✓	✓	✓	✓	✓	✓
	MEDIUM	✓	✓ ^{3,4}	✓ ³	✓	N/A	✓ ⁵
	HIGH	N/A	N/A	N/A	✓	N/A	N/A

✓: Commercially available;

N/A: Not currently available

1 - Analog voice using standard voice service

2 - Possible but not implemented rate range

3 - Covers up to medium end of defined data rate range

4 - Location is a major consideration

5 - Covers up to low end of defined data

Note: This table was developed in the course of the CII project Research

5.3 Hypothetical Case Study #1

This section will discuss a hypothetical case study of a construction project where the contractor is considering incorporating wireless technology onto his jobsite. The first section of this example will describe the project and articulate the information needs that the contractor has identified. It will then eliminate technology from consideration based on table 5.3. The second half of this section will look at some of the other technical issues that a contractor should consider before selecting a technology.

5.3.1 Hypothetical Case Study

It was decided by the CII research team to base our hypothetical example on the construction of a Sulfur Recovery Unit (SRU) inside the confines of an operating crude oil refinery. The refinery is located near a small city. An SRU is used to extract excess sulfur from the oil, and is usually located near the outside of the refinery complex or at least near a road. An SRU has steel towers and holding vessels that can be between three and four stories in height. There are steel pipes and pipe racks throughout an SRU. There are several 1000 horsepower blower units located throughout the facility. These blowers will not be operating during the construction process.

The SRU that is being considered in this example is 150 feet in width and 300 feet in length. The job trailers are located approximately 900 feet away from the SRU. There are pipe racks with 6 to 24 inch pipes in them that are in the line of sight between the trailers and the construction jobsite. The area is shown in Figure 5.1. The owner of the facility has design and quality control representatives that are located in the trailers at this jobsite throughout the day. Most of the materials for use on this project are stored in a warehouse and laydown yard in another area of the refinery approximately one mile from the site.

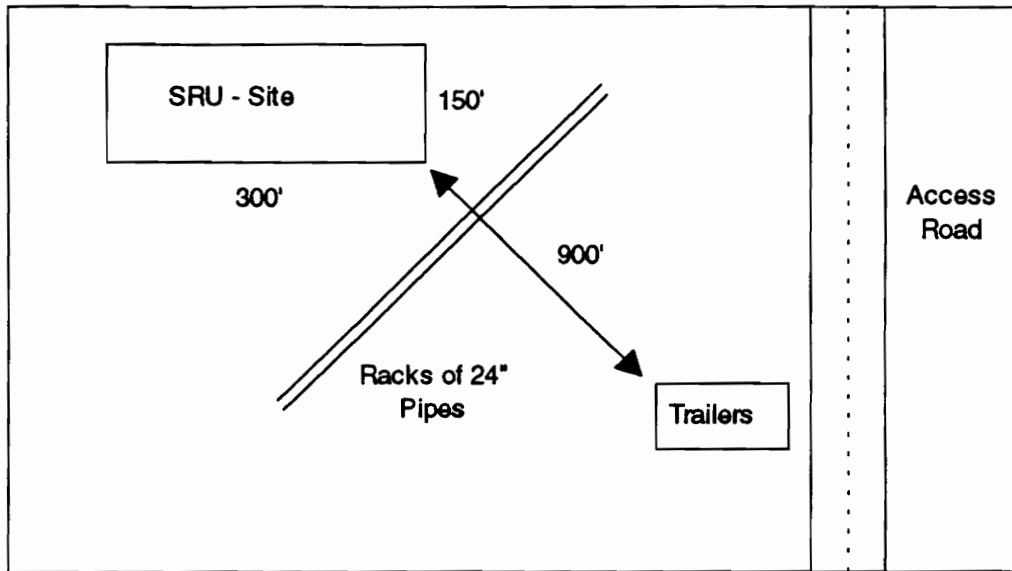


Figure 5.1 Layout of Site for Hypothetical SRU Example

The contractor has approximately fifty people working on this project in five crews per shift. The contractor wants the foremen of each of these crews to have access to the wireless communication system that he chooses. The contractor wishes to meet needs in the following information categories with wireless technology:

- Requests for Information (RFI's)
- Materials Management
- Jobsite Record Keeping
- Quality Control / Quality Assurance

For this example, information subcategories for each category were chosen from Chapter 4. Table 5.4 is a listing of all of the information needs, by subcategory that this contractor has identified. This contractor estimates that only the jobsite record keeping information need will be used on a regular basis (two to three times per shift per foreman) and the rest will be used on an as needed basis.

Table 5.4 Information Needs That Have Been Identified for the Hypothetical Case

Information Category	Information Subcategory	Formats of Info. Transfer	Type (file size)	Delay (mins)	Importance	Data Rate (kbps)	
REQUESTS FOR INFORMATION	1.) Design and Intent Clarification	Voice		< .01	5	8 - 32	
		Video		< .01	1	128 - 10,000	
			Batched Data	Small	< 1	4	0.68
				Medium	< 1	4	13.65
				Large	<10	3	13.65
	3.) Contract Specifications	Voice			< .01	5	8 - 32
					< .01	1	128 - 10,000
		Batched Data	Small	<1	3	0.68	
			Medium	<1	2	13.65	
			Large	NF	1	>1	
	4.) Contract Drawings	Voice			< .01	3	8 - 32
					< .01	1	128 - 10,000
		Batched Data	Small	<1	3	0.68	
			Medium	<1	4	13.65	
			Large	<10	4	13.65	
MATERIALS MANAGEMENT	1.) Access to Company's Material Management Information	Voice		< .01	4	8 - 32	
				< .01	1	128 - 10,000	
		Batched Data	Small	< 1	5	0.68	
			Medium	< 1	3	13.65	
			Large	NF	1	> 1	
	2.) Material Location	Voice			< .01	4	8 - 32
					< .01	1	128 - 10,000
		Batched Data	Small	< 1	5	0.68	
			Medium	< 1	3	13.65	
			Large	NF	1	> 1	
	JOB SITE RECORD KEEPING	1.) Recording Timesheets	Voice		< .01	2	8 - 32
					< .01	1	128 - 10,000
		Batched Data	Small	< 1	5	0.68	
			Medium	NF	1	> 1	
			Large	NF	1	> 1	

Based on the information from Table 5.4, a summary chart for each of the information categories can be formulated. This information is presented in Table 5.5.

Table 5.5 Summary of Information Needs and Maximum Data Rate by Category for the Hypothetical Case

Information Category	Formats of Info. Transfer	Type (file size)	Data Rate (kbps)
1.) Requests for Information	Batched Files	Small	.68
		Medium	13.65
		Large	13.65
2.) Materials Management	Batched Files	Small	.68
		Medium	13.65
		Large	> 1
3.) Jobsite Record Keeping	Batched Files	Small	.68
		Medium	13.65
		Large	> 1
4.) QC / QA	Batched Files	Small	.68
		Medium	13.65
		Large	> 1

If one were to look at Table 5.5, one can see that the maximum data rate required for batched data is 13.65, for a variety of medium and large file transfers. Additionally, this contractor has decided that medium quality voice will serve his purposes.

With this information, the contractor can then consult Table 5.3 and eliminate certain types of technology from consideration. If one were to look at medium QOS for live voice, one could see that the following wireless communication formats can support the need that the contractor has identified:

- Circuit Switched Cellular Modem
- Packet Switched SMR
- CDPD
- Wireless LAN

Because Packet Switched SMR's and CDPD are based on packet switched technology, they may only be able to marginally support the data rates dictated by the information

needs summarized in Table 5.5. However, if the data rate that was required had been low enough for these two methods to support it, they would still be eliminated as viable options because, it was stated that this SRU was being built near a small city. Service for Packet Switched SMR's and CDPD are only typically available in large metropolitan areas. Therefore, the service to support these two wireless communication techniques would not be available at this construction site.

Now that Packet Switched SMR's and CDPD have been eliminated from consideration, the contractor will see in Table 5.3 that he can only use the following:

- Circuit Switched Cellular Modem
- Wireless LAN

The next section will explore some of the nuances that are involved in making a selection from the above list.

5.3.2 Options to Hypothetical Case Investigated

This section will examine some of the other considerations that a company should make before they select a wireless communication system in the hypothetical example.

The Circuit Switched Cellular method requires that standard cellular phone service be available. This site is near a small city, chances are good that there is cellular service available. However, the contractor must be sure of this before he considers this method further. For the purpose of this example, it will be assumed that cellular service is available. The next step that a contractor should take is to find the cost of service from the cellular provider. The explanation said that the contractor would have five different users at any given time. The number of users may effect the pricing that he receives for the service from the cellular provider.

The number of users that the contractor has on his wireless system may also effect the data transmission. By consulting Section 2.2.3 from the CII source document of

wireless communication at the jobsite [DEL96], one can see that the advanced mobile radio system (AMPS) that is currently used in the United States in analog cellular systems allows only 118 channels per cell. Since this contractor has only five users this limitation should not be a tremendous consideration. However, if the contractor were working on a much larger site and needed several hundred foreman to be able to have access, this limitation would become important.

Section 2.4.3.1, of the CII document [DEL96], highlights another issue that the contractor needs to consider for his batched communication. This method is circuit switched and therefore, may not be cost effective to send short batched files. Since most of the cellular service providers in the country charge by the minute, it might become expensive for the contractor to send short batched files.

Cellular modems can only transmit batched data. To meet his live voice needs the contractor has two options. First, since the Circuit Switched Cellular method already requires a service agreement with the cellular provider, the contractor could use this agreement and use cellular phone service to meet his live voice needs. There is a cellular modem available that allows simultaneous data and voice at a reduced data rate.

The contractor must also be aware that because of the rugged environment the large scale propagation issues discussed in Section 2.3.1, of the CII document [DEL96], need to be taken into consideration. Pipe racks, large metal towers and some of the other items that are this hypothetical site might cause propagation problems. Before the contractor purchases equipment for the Circuit Switched Cellular option, he may want to walk through his site as well as other parts of the refinery with a cellular phone and data device to get an idea how well it will perform in the site's environment. If adequate coverage is not available then the contractor needs to work with the service provider to work through the problem and obtain better coverage.

One drawback to this method that contractor needs to consider is that he will be giving each of his foreman a cellular telephone. The contractor would need to be vigilant

to insure that the cellular phones did not get used for personal calls by the foremen or crews. Section 2.3.2, of this thesis, discussed a trucking company that had outfitted its trucks with cellular telephones and found that its drivers often used them for personal calls. The monthly service bill for these phones were very expensive as a result. For cellular data devices, the application software on the computer could be used to limit the locations that can be called, effectively limiting the use of the cellular line to business use only.

The contractor's second option would be to get a voice Specialized Mobile Radio service. This could be as simple as a walkie-talkie to meet his live voice needs. This option would eliminate the possibility of abuse by the foreman because the SMR could only be used to contact the base station.

The contractor would need to invest in hardware in order to be able to use the circuit switched method. He would need to purchase a laptop or pen-tab computer for each of his foremen. In addition he would need to purchase a cellular modem for each computer. Chapter 3, of the CII document [DEL96], can be useful in helping to select the appropriate modem. Table 5.6 is taken from the CII document [DEL96], it shows several different cellular modems. For example, the first modem listed is the Motorola Montana 28.8. This modem has a data rate of 28.8 kbps, which exceeds the 13.65 kbps that is the maximum that the contractor identified. Looking across this table, the contractor can see information about the modem. The last column gives the World Wide Web address on the Internet for the manufacturer. If the contractor wanted more information on the product, he could visit the manufacturer's web page. There are five other modems that are listed for consideration. The only other hardware that the contractor will be required to purchase is a data compatible cellular telephone and the cable to connect the modem to the phone.

The second option that will be discussed is the Wireless LAN technique. Wireless LAN's operate in the unlicensed bands of the spectrum. Therefore, no service providers

are needed and there are no service fees. A drawback to the Wireless LAN method is that it requires additional initial investment in equipment. In addition to the computers, the contractor will need to purchase wireless LAN cards for each foreman. The contractor will also need to purchase access points to the LAN. Due to the size of the site that was described in the example, the contractor will need to purchase at least two access points. Additional access points or repeaters may be necessary to provide adequate coverage, depending on environmental conditions. One other on-going expense that the contractor will need to consider is that he will need to have someone who is responsible for the LAN and its maintenance.

Propagation issues need to be considered with the Wireless LAN as well. If the contractor had problems, he could move the LAN access points to minimize the interference that might be caused by the material and equipment on the site. Also, since Wireless LAN's operate in an unlicensed band, there is the potential to have interference from other users in the band.

Table 5.6 Technical Aspects of Various Cellular Modems (from [DEL96, pp. 61-62])

Manufacturer and Model	Max. Data Rate (kbps)	Data Compression	Error Correction	Fax Support	Voice/Data	Security
Motorola Montana 28.8	28.8	v.42 bis, MNP 5	V.42, MNP 2-4, ETC	V.17, G3 C1/C2	N/A	N/A
AT&T Keep in Touch 28.8	28.8	v.42 bis, MNP 5	V.42, MNP 2-4, ETC	V.17, G3 C1/C2	N/A	N/A
Megahertz XJEM 3288T	28.8	v.42 bis, MNP 5	V.42, MNP 2-4, MNP 10, MNP 10EC, ETC	V.17, G3 C1/C2	N/A	N/A
Microcom TravelCard FAST 28.8	28.8	v.42 bis, MNP 5	V.42, MNP 2-4, MNP 10, MNP 10EC, ETC	V.17, G3 C1/C2	N/A	Dial Access and Enhanced Password connection
Xircom CreditCard 28.8	28.8	v.42 bis, MNP 5	V.42, MNP 2-4, ETC	V.17, G3 C1/C2	N/A	N/A
TDK Systems DataVoice 28.8	28.8	v.42 bis, MNP 5	V.42, MNP 2-4, MNP 10EC, ETC	V.17, G3 C1/C2	Yes	N/A

N/A - Information Not Available

Table 5.6 (Continued)

Manufacturer and Model	Compatible Cellular Phones	Network Interface	Comm. Software	Special Features	WWW Address
Motorola Montana 28.8	Motorola, AT&T, NEC, OKI	PSTN	Included	Download data from Motorola pagers	www.mot.com/MIMS/ISG/Products/montana
AT&T Keep in Touch 28.8	Motorola, AT&T, NEC, OKI, Nokia	PSTN	Included		www.paradyne.com
Megahertz XJEM 3288T	Motorola, AT&T, NEC, Nokia, Radio Shack	PSTN	Included	Integrated 10 mbps Ethernet for wireline use	www.megahertz.com
Microcom TravelCard FAST 28.8	N/A	PSTN	Included	Builtin security	www.microcom.com
Xircom CreditCard 28.8	N/A	PSTN	Included		www.xircom.com
TDK Systems DataVoice 28.8	Motorola, AT&T, NEC, OKI, Ericsson, Fujitsu, GE	PSTN	Included	Simultaneous voice and data	www.tdksystems.com

Wireless LAN's currently do not have the capability to transmit live voice. Therefore, as with the Circuit Switched Cellular option, another means of live voice will need to be used. The same two options, cellular phone service or a SMR, are available to augment the Wireless LAN option.

If the contractor were to decide to implement the Wireless LAN option, he could consult Table 5.7, which is taken from the CII document [DEL96], to look at some of the outdoor wireless LAN's that are currently available. There are seven different LAN's that are listed. The second one listed is the AirNet ArLAN 630-2400. The first column shows that this model is capable of a data rate of ½ Mbps or 500 kbps. This data rate greatly exceeds the 13.65 kbps that the contractor has identified as his maximum requirement.

The rest of the table gives more information about the product. This table also gives the World Wide Web address for the manufacturer.

One final issue that will be discussed is cost. For the Circuit Switched Cellular modem method, in addition to the computers for each foreman the contractor will be required to purchase a cellular modem (~\$200 - \$300), a connection cable (~ \$50) and a harsh environment cellular telephone (~\$400 - \$500). For the Wireless LAN method in addition to the computers, for each foreman the contractor will need to purchase a wireless LAN card (~\$400), as well as access points to the LAN (~\$1,500 each). These are just an approximation of the hardware expenses at the time of publication. It is important to note that there will be software, setup, maintenance and LAN support expenses to consider that will probably greatly outweigh the initial hardware expenses for any of the wireless communication systems that have been discussed.

This section has outlined some issues that the contractor should consider before purchasing wireless equipment. If a contractor were to look at data rates alone, he might wind up purchasing equipment that he cannot use. For example, if the contractor in the hypothetical case had purchased CDPD equipment before fully investigating his situation, he would have expensive wireless equipment that he could not use on this job. In conclusion, a contractor needs to look at many issues when investing in a wireless communication system.

Table 5.7 Technical Aspects of Various Wireless LANs (from [DEL96, p. 73])

Manufacturer and Model	Data Rate / channel (Min/Max)	No. of Channels	Access Method	Supported Protocols	Range (omni/dir. ant) / Power	WWW Address
AiroNet ArLAN 630-900	215 / 860 Kbps (US) 172 / 215 Kbps (Aus)	12 (US) 7 (Aus)	DS SS	Ethernet / Token Ring	600m / 10 km / 1W	www.teleport.com/~nts/aironet.html
AiroNet ArLAN 630-2400	1 / 2 Mbps (US, ETSI, Japan)	5 (US, ETSI) 1 (Jp)	DS SS	Ethernet / Token Ring	300m / 5 km / 100 mW	www.teleport.com/~nts/aironet.html
BreezeCom BreezeNet	3 Mbps	Not avail.	FH SS	Ethernet	1 - 10 km / 100 mW ¹	www.breezecom.com/wb10ds.htm
Karlnet Wireless KarlBridge	2 Mbps (both 900 /2400 MHz versions)	Not avail.	DS SS	Ethernet	16 km / 250 mW	www.karlnet.com/wirelessKB.html
Proxim RangeLink	1.6 Mbps	15	FH SS	Ethernet	5 km / 100 mW	www.proxim.com/proxim/products/rnglnk/overview/rangelnk.htm
Solectek AIRLAN Bridge Plus	2 Mbps (900 MHz)	Not avail.	DS SS	Ethernet SNMP compliant	4.8 km / 4 W ERP	www.cts.com/browse/solectek/plus.htm
Solectek AIRLAN Bridge Ultra	2 Mbps (2.4 GHz)	3	DS SS	Ethernet SNMP compliant	40 km / 4 W ERP	www.cts.com/browse/solectek/bridges.htm

¹ The BreezNet product has a basic range of 1 Km. with an omnidirectional antenna when fed at 100 mW ERP. With high gain directional antennas, it has a range of 10 km in the US with a ERP of 4 W and 2.5 km in Europe with a ERP of 100 mW.

5.4 Hypothetical Case Study # 2

The first hypothetical case was based solely on the information needs that were identified in Chapter 4. A construction company might have information needs other than those listed in Chapter 4. Additionally, a construction company may desire information faster or slower than presented in the charts in Chapter 4. This is a second hypothetical case that is presented to show how a company could use the tools presented in Chapter 4 to articulate their own information needs in such a way that they may use the rest of this document to investigate wireless technology.

STEP 1 The construction company must identify its information needs. A construction company could choose to use a table similar to the ones that were presented in Chapter 4 to articulate what categories of information needs they hope to address using wireless technology. The company would fill in the “Information Category” column with the information need has been identified.

STEP 2 The second step that the company needs to do is identify the formats (voice, video, or batched files) that it wants to use to meet each information need.

STEP 3 The next thing that they will need to do is identify how fast they would need each size batched file to be transmitted. This time was defined as the ‘Delay Rating’ in Section 4.1. The contractor can fill his allowable Delay Rating in the appropriate column for each size batched file.

STEP 4 Once these items are determined, the data rate required can be calculated using Equation 4.1. The data rates can be filled in to the appropriate column on the work sheet.

STEP 5 The next thing that a contractor should do is to determine the importance of each format for each information need that he has identified. A contractor may identify a certain information need that he feels as minimally important. However, that particular information need might require a data rate that is much higher than any of the other needs he has identified. Since this information need has been deemed less important by the contractor, he may want to disregard it because of its high data rate.

STEP 6 The final step that a contractor should do is determine the quality of service that he desires for his live voice and video transmissions. Table 5.2 gives the data rates associated with each level of quality of service for voice and video.

Once the contractor has identified all of the information needs that he hopes to address using wireless technology, he would want to find the highest data rate requirements for each format of information. This summary can be put into a chart similar to Table 5.1. This will allow the contractor to identify the highest data rate he hopes to achieve from his wireless communication system. It should be noted that live voice and video are defined by what quality of service the contractor wants. Therefore the contractor can refer to Table 5.2 to determine the data rates required for live voice and video applications.

An example follows:

EXAMPLE : ABC Construction Company, Inc. is considering investing in some wireless equipment to improve its jobsite communication. The first step ABC did was to identify the information needs that they hope to address by their investment into a wireless communication system. These needs are:

- Having their foremen perform all timesheets in the field.

- Transferring drawings from the trailer to their foremen in the field.
- Having voice communication with their foremen.
- Having their foremen submit their progress reports from the field with digital pictures.

These needs could be inserted into a chart similar to the ones used in Chapter 4. An example of this is shown in Figure 5.2.

Information Need Category	Formats of Info. Transfer	Type (file size)	Delay	Importance	Data Rate (kbps)
Timesheets completed in the field.	Voice				
	Video				
	Batched Data	Small			
		Medium			
Drawings transferred to the field	Voice				
	Video				
	Batched Data	Small			
		Medium			
Large					
Voice Contact with Foreman	Voice				
	Video				
	Batched Data	Small			
		Medium			
Large					
Progress Reports with digital pictures	Voice				
	Video				
	Batched Data	Small			
		Medium			
Large					

Figure 5.2 Example of Articulation of Information Needs

Once this contractor has identified his information needs, Step 2 is to determine what format he wants the information transfer for each different type of information need. The file sizes are defined in Section 4.1. The contractor has identified the following as the formats of file transfer he would like for each information need.

- Timesheets can be completed using a small batch file transfer.
- Drawings can be transferred using a medium or large batch transfer.
- Communication with the foremen will require live voice.

- Progress reports with digital pictures will require small, medium and large batch transfers.

Step 3 is for ABC to identify the amount of delay that would be allowable for the transfer of each type of file. The scale for delay rating that was used in Chapter 4 is helpful because each of its divisions are an order of magnitude. Figure 5.3 shows an updated information needs table to include the delay rating. Any delay ratings that are shaded means this contractor has not identified that format for the given information need.

Information Need Category	Formats of Info. Transfer	Type	Delay	Importance	Data Rate Required
Timesheets completed in the field.	Voice				
	Video				
	Batched Data	Small	<10 mins.		
		Medium			
Drawings transferred to the field	Voice				
	Video				
	Batched Data	Small			
		Medium	<1 min.		
Large		<10 mins.			
Voice Contact with Foreman	Voice		<.01 mins.		
	Video				
	Batched Data	Small			
		Medium			
Large					
Progress Reports with digital pictures	Voice				
	Video				
	Batched Data	Small	<1 min.		
		Medium	<1 min.		
Large		<1 min.			

Figure 5.3 Example of Articulation of Information Needs with Formats and Allowable Delays Included

Step 4, would be for ABC to calculate the data rates that are required for each different format that that has been identified. This is done using Equation 4.1.

Step 5 is for the contractor to assign the importance that he places on each of the information needs that he has articulated. This data rates and importance are included in Figure 5.4.

The final step is to identify the quality of service for live voice and video. These data may be obtained from Table 5.2 For this example, the contractor only desires low quality of service for voice and did not identify video as a need.

Now that he has filled in all of the information in the information needs chart, the next thing that he should do is to complete a summary chart similar to Table 5.1. In this chart he will show the highest data rates for each batched file size that is required for any of the information needs that he has identified. This summary will define the data rate parameters that the contractor will need to consider when looking for wireless technology.

Information Need Category	Formats of Info. Transfer	Type	Delay	Importance	Data Rate Required
Timesheets completed in the field.	Voice				
	Video				
	Batched Data	Small	<10 mins.	4	.068 kbps
		Medium			
Large					
Drawings transferred to the field	Voice				
	Video				
	Batched Data	Small			
		Medium	<1 min.	3	6.8 kbps
Large		<10 mins	3	13.7 kbps	
Voice Contact with Foreman	Voice		< .01 mins.	5	8 kbps
	Video				
	Batched Data	Small			
		Medium			
Large					
Progress Reports with digital pictures	Voice				
	Video				
	Batched Data	Small	< 1min.	5	.68 kbps
		Medium	< 1min.	4	6.8 kbps
Large		< 1min.	1	136.5 kbps	

Figure 5.4 Completed Information Needs Articulation Chart

Information Category	Format of Info. Transfer	Type	Data Rate Required
Summary for All Categories	Batched Files	Small	.68
		Medium	6.8
		Large	136.5

Figure 5.5 Summary of Maximum Required Data Rates For Information Needs

This example illustrates the thinking and methodology that was employed in Chapter 4 during the articulation of information needs. This example was included to show a contractor that they are not limited to the information needs that were articulated in that chapter. It also gives contractors the means to use the rest of the information in this document to assess what forms of wireless technology might meet their needs.

By examining the information in Figure 5.5, the following data rates were identified: .68 kbps for small batched files, 6.8 kbps for medium files and 136.5 kbps for large files.

Now ABC is ready to consult Table 5.3 to determine what wireless technology can be eliminated from consideration. If ABC examines voice first, then by looking at low QOS for voice the can see that the only technology that needs to be eliminated from consideration is paging.

For the purpose of example, each of the batched file sizes will be considered separately. In reality, a company would probably look at its highest data rate requirement for the three because it will be the constraining factor in eliminating technology. Figure 5.5 show that or the small data files a data rate of .68 kbps is acceptable. This data rate falls into the low data rate range in Table 5.3. At this data rate requirement, any of the technology that have been identified have the potential to meet these information needs.

Figure 5.5 shows that the medium sized files require a data rate of 6.8 kbps, which falls into the medium data rate range in Table 5.3. Based on the information there, paging and satellite communications need to be eliminated from consideration.

For large files, Figure 5.5 shows that a data rate of 136.5 kbps, therefore, only a fast data rate will suffice. Table 5.3 shows that all of the technology can be eliminated from consideration except the wireless LAN. At this point ABC may want to look at the importance that has been placed on this need. According to Figure 5.4, it rated as the only large batched file transfer that was identified and as very unimportant. Because this information need has such a high data rate requirement and low importance, the company may want to reconsider the delay rating associated with this information need.

In this example, technology has only been eliminated from consideration, no technology has been selected yet because of the technical items that need to be considered. For example, ABC might decide to investigate the Cellular Digital Packet Data (CDPD) technology. The project that they plan to deploy this technology on is located in a small town in Wyoming. Since CDPD is currently only available in large markets, it is probably not a good choice for this jobsite, even though it can achieve the data rates required.

Once the company identifies the technology that it wants to use, they can refer to Chapter 3, of the CII document [DEL96], to select the appropriate hardware to meet its needs. For example, ABC finds out there is CDPD service available at its site and decides to use it. The company could consult Table 5.8, taken from the CII document [DEL96]. This table gives information about four CDPD modems. The third one in the chart is the Sierra Wireless MP 200. The first column shows that it has a data rate capability of 19.2 kbps which will meet all of the required data rates for ABC's information needs except large batched files. This table gives other information about the modems, including the manufacturer's World Wide Web locations. The company would need to provide an alternate form of voice communication such as cellular telephones or an SMR because CDPD is only for batched data transmission.

Table 5.8 Technical Aspects of Various CDPD Modems (from [DEL96, p.66])

Manufacturer and Model	Max. Data Rate (kbps)	Comm. Software	Voice/ Data	Fax Support	Security	WWW Address
PCSI Ubiquity 1000	19.2	TCP/IP via SLIP	Both	V.17, G3 C1/C2	Inherent in the Protocol	www.pcsi.com
Sierra Wireless Pocket Plus 210	19.2	TCP/IP via SLIP AT-style commands	Both	V.17, G3 C1	Inherent in the Protocol	www.sierrawireless.com
Sierra Wireless MP 200	19.2	TCP/IP via SLIP AT-style commands	Both	V.17, G3 C1	Inherent in the Protocol	www.sierrawireless.com
IBM Wireless Modem for Cellular/ CDPD	19.2	TCP/IP QucikLink Mobile Fax/Modem	Data	V.17, G3 C1/C2	Inherent in the Protocol	www.raleigh.ibm.com/cel/celspec1.html

5.5 Conclusion

This chapter has illustrated how a construction company can use the tools presented in this document to articulate what information needs that they want to satisfy wirelessly. Next, it showed how to determine the data rates that each format of information transfer requires, based on the needs that have been articulated. Next it was shown how to eliminate different types of wireless technology from consideration based on the data rates. Finally, two hypothetical cases studies involving construction companies that are considering incorporating wireless technology were investigated. The first case study used information needs that were identified in Chapter 4. The emphasis was on eliminating wireless technology from consideration and then looking at the other factors that will effect the selection of wireless technology. The emphasis of the second

hypothetical case was to illustrate how a construction company can customize their own information needs using the methodology that was used in Chapter 4.

This chapter was written to show the process that a construction company should go through to make an informed selection of wireless technology. Because of the dynamic nature of the construction industry, no two jobsites are alike. Therefore, wireless technology that has worked on one site might not necessarily work on another. Though some wireless solutions may work on different jobsites, the process outlined in this chapter is meant to be used on a job to job basis.

One final item to consider is that there are many technical issues to consider when choosing a wireless communication system. The information in this document is intended to provide construction companies the in-house technical background to make an informed decision if they choose to consider wireless communication. It is not meant to make a reader an expert in the wireless communication field. If a construction company is considering incorporating wireless communication onto their jobsite they may want to consider hiring a wireless communication consultant to insure that they invest in technology that is going to work for them.

Chapter 6 Summary and Conclusions

6.1 Summary

This thesis meets the two goals that were defined as its purpose. The first goal was to articulate the information needs that a construction project might have at a typical jobsite. The other goal was to take the information needs and come up with a methodology to identify wireless technology that could potentially meet the information needs.

6.1.1 Summary of Information Needs Articulation

One of the primary goals of this project was to articulate the information needs that exist between the trailer and the jobsite at a construction site. The Construction Industry Institute research team that was overseeing this project selected the Lyondell - Citgo Refinery projects as a good site to collect data for the identification of information needs. The LCR site was a “mega - project” and was chosen because it inherently had many information needs challenges.

Based on the information gathered at LCR, many different types of information needs were identified and articulated in Chapter 4. Another important feature in Chapter 4 is the format that was developed to articulate these information needs. The tables that appear in Chapter 4 show the different variety of items that a construction company needs to think about when it identifies its own information needs between the trailer and the field. The ten information categories that were presented in Chapter 4 are not meant to be a definitive list of all the information needs that might exist at any construction site rather, they are meant to be a guide that a construction company can use to identify and articulate its own information needs.

6.1.2 Summary of Methodology of Identifying Wireless Technology to Meet Information Needs

A construction company might have different information needs than the ones articulated in Chapter 4. Therefore, in Chapter 5, a methodology was presented by which a construction company has the means to articulate its own information needs. The methodology outlined the steps that were used in Chapter 4 to articulate the information needs and calculate the data rates associated with a given information need. A construction company is encouraged to use the information presented in Chapter 4, however, Chapter 5 gives them the means to be able to identify their own information needs.

The next item that was presented was how to eliminate different types of wireless technology from consideration based solely on the data rates that the information needs require. This section was intended to show how a company could limit the wireless options that it should consider. Data rates are not the only thing that a company needs to take into consideration when choosing wireless technology, there are many other aspects that need to be considered.

Finally, two hypothetical case studies were presented. The first study illustrated the different steps that a company may want to take when considering investing in wireless technology. The second illustrated how a company can articulate their own information needs.

6.2 Conclusions

6.2.1 How the Construction Industry Can Benefit from Using Wireless Technology

There are many ways that the construction industry might benefit from incorporating wireless technology onto its jobsites. Wireless technology will permit

information to flow in a faster, more timely manner between the field and the trailer. Wireless techniques will allow the two parties to communicate without leaving where they are at. This alone will make it more convenient for the two parties to communicate with one another. Additionally, the speed with which information can be communicated can be increased through the use of wireless technology.

Second, it has the potential to provide the personnel in the field with information while they are actually performing work. This means that if a crew in the field has a problem, they have the means to consult with the trailer for a solution without having to actually go to the trailer. The faster that answers to problems can be received, the less likely it is that a crew will need to stand idle to wait for answers to problems.

One final consideration is that if supervisory personnel, foremen and superintendents, need to leave the field less often their crews will be unsupervised less often. If a foreman could get his questions answered and submit paperwork without having to leave the field, then his crew would not go unattended. Wireless technology is a means to allow the supervisory personnel at a construction site to stay in the field more. If the crews are supervised more of the time, a contractor may increase the productivity of his crews.

6.2.2 When Not to Consider Using Wireless Technology

If a construction company is considering using wireless technology on its jobsite it should examine carefully the applications that are being considered for wireless use. An application that is being considered for wireless technology should have two important components. First, it should be an application that cannot be done using hardwired means. If it is an application that needs to be performed in the field, it generally cannot be done using hardwired methods. Second, it needs to be an application that is time critical. This means that it must be an application where time is of the essence. If time is not a major

consideration, then the information could be transported between the trailer and the field, using traditional methods.

The primary reason for mentioning these two criteria is financial. Many of the wireless technologies that have been considered require a service fee that must be paid when they are in use. If a given transfer of information can be done using hardwired means it will be less expensive than using wireless means. If the information is not time critical, then it can wait until a break or the end of a shift when a foreman would normally be going to the trailer.

It is important that a construction company insure that wireless technology is the best way to communicate different types of information. Service fees and other expenses related to wireless communication systems can become a large expense. Therefore, a construction company should want to insure that wireless technology is being used only when it is absolutely necessary.

6.2.3 Importance of Cost Versus Benefit

It is important to consider the trade-off between the “value” of transmitting the information wirelessly on demand against the “cost” of transmitting it. Wireless communication is not an inexpensive proposition. There are initial equipment expenses, expenses associated with service fees and maintenance, and indirect expenses that need to be considered.

Some of the costs of investing in wireless technology that need to be considered are:

- The purchase of hardware and software, a one time cost.
- The maintenance and upgrading of hardware, an on-going cost.
- The upgrading and licensing of software, an on-going cost.
- The fees of wireless service providers, an on-going cost.
- The salaries of in-house technical support personnel, an on-going cost.

- The training of the users, an on-going cost.
- The fees to a specialized wireless consultant, an on-going cost.

The following is a way that a company might approach the cost-benefit analysis for wireless communication. Figure 6.1 is a graph that shows the value and cost of information versus the time of day that the information is sent. In this example, a foreman has information that he needs sent to the trailer at 8:00 AM. The value of this information at 8:00 is $V1$. If the foreman had access to a wireless information system, he could immediately download that information to the trailer at a cost of $C1$. If he did not have access to wireless information, he might have to wait until the end of his shift to bring the information to the trailer. The value of the information has decreased as depicted by $V2$, because of the nine hour time delay. The cost of delivering the information has also decreased, as shown by $C2$. The company must decide if the additional cost of transmitting the information is worth the added value of the information. This example examines the cost-benefit comparison by looking at the decrease of the value of the information over time. The question is: is $\Delta 1 > \Delta 2$?

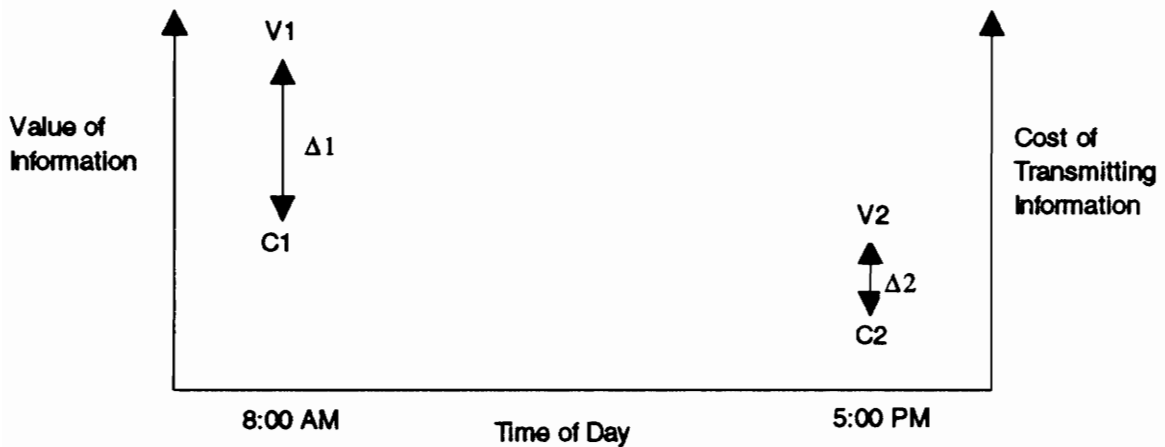


Figure 6.1 Cost-Benefit Comparison

The next example will look at the productivity that is lost if the foreman needs to leave the field to deliver information to the trailer. Figure 6.2 is set up the same way as Figure 6.1. However, in this example, the information that the foreman needed to bring to the trailer could not wait until the end of the day. If the foreman had access to wireless communication he could download the information at 8:00, as soon as he finds it at a cost of C_1 . If the foreman did not have wireless communication capabilities, he would have to leave the field and bring the information to the trailer at 8:30. The value of the information has not changed much between V_1 and V_2 . However, when the foreman leaves the field, his crew's productivity will decrease and the cost of transmitting the information increases from C_1 to C_2 . This is another way that a company might want to approach their analysis of wireless communication. . The question again is: is $\Delta 1 > \Delta 2$?

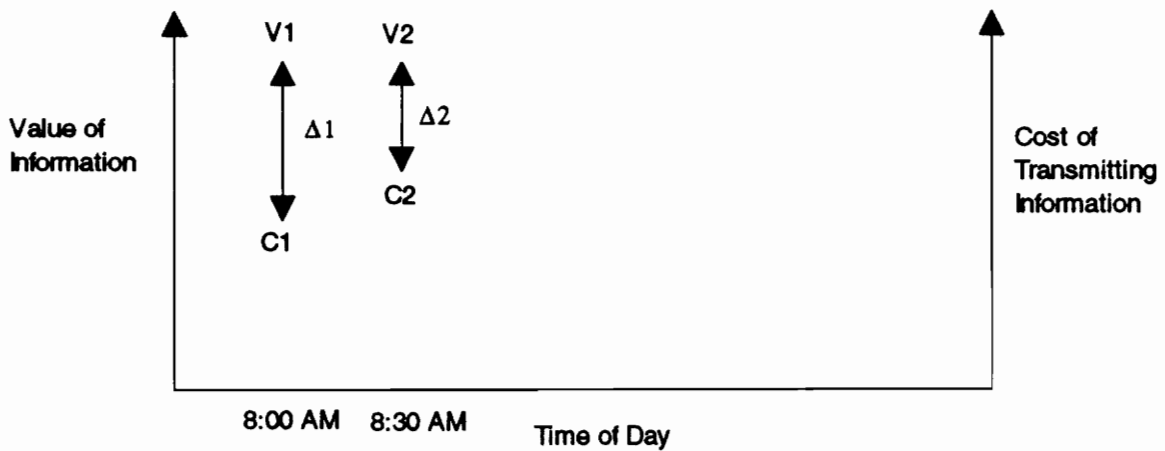


Figure 6.2 Cost-Benefit Example 2

Wireless communication is a field that is making advances every day. The construction industry can benefit greatly by incorporating wireless communication on to its jobsites. However, a contractor should not assume that wireless communication technology is the best answer for his information needs at a jobsite. He should investigate first to see if he can derive greater benefits from wireless technology than it will cost him.

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Appendix A

Questionnaire From LCR Data Reconnaissance Visit

Questionnaire

Wireless Technology on the Jobsite

- I.) Explanation - The following survey is designed to help assess your information and communication "wants and needs" on the jobsite. This survey is for a research project that is looking for ways to improve the flow of information on the jobsite, and between the jobsite and the job trailer. Please consider this a "wish list," and answer the questions with any want or need, no matter how impossible or unlikely they may seem. All answers will remain strictly confidential.

- II.) Preliminary and Personal Information - The following questions are for background and grouping purposes.
 - 1.) What is your name?

 - 2.) What is your current position title?

 - 3.) What is your job description?

 - 4.) How many years experience do you have in your current position?

 - 5.) What other positions have you held in the past?

 - 6.) How many years experience do you have overall?

7.) What are the primary responsibilities of your current position?

8.) What other tasks are involved with your position (e.g. record keeping, payroll, etc.)? [Please indicate how much time each of these activities occupy in an average day.]

9.) Where are you located when you physically perform the tasks in question 8?

10.) Where do you spend most of your time during an average day at work?

11.) Of all of your duties what is the one thing that you like performing least?

12.) What wireless technology have you used in your job or at home? (Please check all that apply.)

_____ Walkie Talkie

_____ Cellular Telephone

_____ Cordless Telephone

_____ Pagers / Beepers

_____ Other (Specify)

III. Below are listed several groups of tasks that are usually found on most job sites. For each category please list what information you could use from that category to help you perform your job more efficiently or accurately. For each item that you list please include the following two pieces of information:

A. What would be the best format for you to receive the required information

- 1 - hardcopy
- 2 - voice
- 3 - electronic text documents
- 4 - electronic images (CAD drawings)
- 5 - photographs
- 6 - video
- 7 - other (please specify)

B. A rank of 1 to 5 as to how much of an impact delay on obtaining this information would have on your job.

Please use the following as a guideline for your ranking

- 1 - little or no impact
- 2 - some impact
- 3 - average impact
- 4 - more than average impact
- 5 - tremendous impact

Example:

Category	Explanation	Format	Rank
Contract Administration	Differing Site Condition Clauses	3	3

CATEGORY (Examples)	EXPLANATION	FORMAT	RANK
1) Contract Administration (Contract Documents, Contract Drawings, Sub-Contractor Documents, Schedule of Bid Items, Supplier Agreements, Change Orders, Work Authorization, etc.)			
2) Scheduling / Planning (CPM Schedules, Site Layout Plans, Work Package Plans, Progress Measurement, Progress Payments, etc.)			
3) Equipment Management and Coordination (Equipment Availability, Rental Agreements, etc.)			
4) Cost Control (Progress Recording, Budgets, Estimating, etc.)			
5) Subcontractor Information (Work Package Information, Sub-Scheduling, Progress Reporting, etc.)			
6) Drawings (Contract Drawings, 2-D and 3-D CAD drawings, Construction Drawings, etc.)			
7) Specifications (CSI Documents, Project Specific Specs., Vendor Catalogs, Material Takeoffs, etc.)			
8) Material Ordering (Delivery Scheduling and Coordination, Direct Access to Vendors, etc.)			
9) Material Inventory (On-site Inventory Control, Warehouse Inventory Access, etc.)			
10) Material Receiving (Inventory Updating, Payment Authorization, On-site Storage Coordination, etc.)			

FORMATS 1 - Hardcopy, 2 - Voice, 3 - Elec Text, 4 - Elec Images (CAD), 5 - Photographs, 6 - Video, 7 - Other (Specify)
RANK 1 - Little or No Impact, 2 - Some Impact, 3 - Average Impact, 4 - More than Average Impact, 5 - Tremendous Impact

CATEGORY (Examples)	EXPLANATION	FORMAT	RANK
11) Safety (Safety Incident Reporting, Access to Safety Procedures, Corrective Actions, etc.)			
12) Quality Control / Quality Assurance (Specification Lists, As Builts, Inspection Data, etc.)			
13) Other (Please Specify)			

FORMATS 1 - Hardcopy, 2 - Voice, 3 - Elec Text, 4 - Elec Images (CAD), 5 - Photographs, 6 - Video, 7 - Other (Specify)
RANK 1 - Little or No Impact, 2 - Some Impact, 3 - Average Impact, 4 - More than Average Impact, 5 - Tremendous Impact

IV In this next section, we have listed several ways to transfer information. Please associate these formats with any job that they might be useful. Please also associate a rank of 1 to 5 as to how useful this information would be.

Please use the following as a guideline for your ranking

- 1 - little or no impact
- 2 - some impact
- 3 - average impact
- 4 - more than average impact
- 5 - tremendous impact

Example:

Format		Rank
Electronic Video	1. Site Inspection	3
	2. Safety Checks	4
	3. Productivity Studies	1

FORMAT	JOBS USED FOR	RANK
Paper Copy		
Electronic Voice Communication		
Electronic Images		
Electronic Still Photos		
Electronic Video		
Electronic (2D and 3D)		
Electronic Text Documents		

RANK: 1 - Little or No Impact, 2 - Some Impact, 3 - Average Impact,
4 - More than Average Impact, 5 - Tremendous Impact

V If you have any other thoughts or comments please make them now

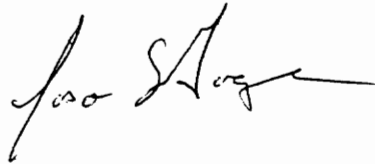
VI. An important aspect of this study is to find effective ways to communicate information to and from the job site in real time for decision making purposes. Below are listed several tasks that require evaluation and decisions to be made in real time. On the horizontal are five methods of communicating information in real time. For each task please rank the five methods in order of practicability as a method for communicating the information associated with that task. (1 being most preferable, 5 being least preferable.)

- **Method 1 - Visual On Site Inspection** - This requires the decision-maker to be at the site to make the decision
- **Method 2 - Voice Communication** - This would allow the decision maker to communicate verbally only with personnel on the job site. Decision-maker would not be able to see the job site.
- **Method 3 - Still Pictures and Voice** This would allow personnel on the job site to send pictures directly from the site to the decision-maker. It would also allow for voice communication as described in Method 2.
- **Method 4- Full Motion Video and Voice** - This would allow personnel from the job site to send video to the decision-maker. This method would also allow for voice communication as described in method 2.
- **Method 5 - White Boarding** - This is an interactive technique that allows decision-makers to communicate with personnel on the job site through the use of personal computers. Both parties view the same document on their computer. Both parties may make alterations or ask questions about the given document (drawing, specification, etc.). This method can be used with or without voice communication as described in Method 2.

TASK	SITE VISIT	VOICE ONLY	STILL PICTURES & VOICE	VIDEO & VOICE	WHITE BOARDING
Example: Material Inspection	3	5	1	2	4
1.) Inspection of Completed Work					
2.) Engineering / Architecture Clarification and Questions					
a.) Drawings					
b.) Works in Progress					
c.) Specifications					
d.) Change Order Requests / Clarification					
e.) General Questions					
3.) Safety Inspections / Investigation					
4.) Supply and Material					
5.) Quality Control / Assurance Inspection					
6.) Schedule Updates / As-Built Information					
7.) Punch Lists					
8.) Other (Specify)					

VITA

Jason Saunders Gagnon was born in Beverly, Massachusetts in June, 1969 to Mr. and Mrs. Peter and Marilyn Gagnon. He graduated from Courtland High School in Fredericksburg, Virginia in June 1987. He received a Bachelor of Science degree in Civil Engineering from Virginia Polytechnic Institute and State University in May, 1993. He will receive a Master of Science Degree from Virginia Tech in December, 1996. After receiving his degree he hopes to work in the construction industry in company and project management or project controls. Eventually, he hopes to earn his doctorate in Civil Engineering.

A handwritten signature in black ink, appearing to read "Jason Gagnon", with a long horizontal flourish extending to the right.