



Wireless Communication and Computing at the Construction Jobsite

A Final Report
to the

Construction Industry Institute

University of Texas at Austin
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Submitted by:

Dr. Jesus M. de la Garza
Charles E. Via Department of Civil Engineering
Virginia Polytechnic Institute and State University
Blacksburg, Virginia

and

Dr. Ivan Howitt
Bradley Department of Electrical Engineering
Mobile and Portable Radio Research Group
Virginia Polytechnic Institute and State University
Blacksburg, Virginia

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Executive Summary

For many years, the walkie-talkie has been synonymous with the construction industry. During jobsite project execution, there are three variables which can either hinder or facilitate successful results, namely, quality, quantity, and timing of information. Wireless data communications technology is capable of delivering just-in-time information within the "last mile" between the trailer and a desired location on the jobsite.

This study surveyed information needs at the jobsite, emerging wireless data communications technology, and assessed the extent to which wireless data technology can fulfill the information needs of the jobsite. Two examples are included to illustrate how to match a set of information needs with appropriate wireless technology.

The study organized jobsite information needs into the following ten categories: a) Requests for Information; b) Materials Management; c) Equipment Management; d) Cost Management; e) Schedule and Means & Methods; f) Jobsite Record Keeping; g) Submittals; h) Safety; i) QC/QA; and k) Future Trends. Each category was analyzed in terms of its appropriateness to take advantage of wireless technology. The four formats considered to transmit information wirelessly were: a) live voice; b) live video; c) batched data; and d) live data.

A representative inventory of current wireless communication technology was developed and classified into the following five classes: a) Circuit-Switched Wireless Data Systems; b) Packet-Switched Wireless Data Systems—this class was further subdivided into Specialized Mobile Radio Systems and into Cellular Digital Packet Data Systems; c) Wireless Local Area Networks; d) Paging Systems; and e) Satellite-based Data Communications. A Primer for wireless communications covering both fundamental and advanced communications concepts was also developed to enable a better understanding of the issues involved in making trade-offs while configuring a wireless jobsite communication system.

The first example presented in this document shows how a contractor can define a subset of information needs by choosing from those already articulated herein and determine if a given wireless technology should even be considered as a viable way of meeting the information needs that such company has. The second example presents a more generic six-step methodology allowing a company to articulate and analyze their own information needs and to match those with current wireless hardware.

The Construction Industry at-large will profit from leveraging walkie-talkie wireless *voice* communication with wireless *data* communication. Wireless technology like Cellular Modems, Wireless LANs, CDPD Modems, Pagers, and Satellites can do it now. For a given construction firm, what is important is to understand that there is a trade-off between the *value* of information and the *cost* of obtaining it. While *value* and *cost* are time dependent variables, the marginal benefit of obtaining the information wirelessly must exceed the marginal benefit of conventional practice.

1. Introduction

1.1 Problem Statement

For many years, the walkie-talkie has been synonymous with the construction industry. As a result, wireless voice communication between members of the construction team at the jobsite is a well-established technology. However, in the last few years, remarkable progress in wireless data communications technology has made possible the provision of new wireless information services within the jobsite. The advent of digital technology supports services ranging from messaging (e.g., queries to suppliers to check on the delivery of materials) to full video (e.g., remote inspection of the construction site by the owner's representative).

During jobsite project execution, there are three variables which can either hinder or facilitate successful results, namely, quality, quantity, and timing of information. Current paper-based jobsite construction processes are becoming obsolete as they are unable to deliver just-in-time information. The paper-based pipeline of information is clogged, hence creating an information deficit. A shift to an electronic-based exchange of information can help alleviate the timely delivering and accessing of relevant amounts of information.

Wireless data communications technology is capable of enabling on-demand access to relevant amounts of project information by all parties (e.g., the contractor, designer, construction manager and owner) at any location (e.g., field, job trailer, corporate office).

Applications of wireless data communications technology include personal and portable computing devices (PPCDs), capable of downloading, uploading, and displaying project-specific information like CAD images of the project drawings, hypertext-based project specifications, product and vendor catalogs, digital still images, video images, and voice clips.

For the most part, the wireless portion of the communications link will serve as the "last mile" from a network connection within the trailer to the desired location on the jobsite. Wired telephone and/or Internet links would still carry data traffic from the jobsite to desired off-site locations.

Because of the nature of wireless PPCDs, they will leverage information-rich jobsite construction processes by delivering just-in-time information anywhere, anytime, and to anyone involved with a given project.

Because timely access to information is what keeps relevant information from becoming irrelevant, applications of wireless data communications technology have the potential of reaping more productivity benefits than the ones achieved already by applications of wireless voice communications technology, e.g., walkie-talkies.

All parties involved in a constructed facility are suppliers and consumers of information. Hence, Owners, Designers, Contractors, Suppliers, and Construction Managers will benefit substantially from having the means to deliver and access information wherever they are whenever they need to.

1.2 Purpose, Scope and Objectives

The purpose of this study was to assess the imminent applicability spectrum of wireless data communication technology at the jobsite.

This specific objectives of this study were to conduct:

- 1) a survey of information needs at the jobsite with a focus on type, amount, quality, and timeliness;
- 2) a survey of emerging wireless data communications technology; and
- 3) an assessment of the extent to which wireless data technology can fulfill the information needs of the jobsite.

The study was limited in scope in that it has concentrated primarily on the jobsite information needs of the Industrial Process construction sector. To this effect, the Lyondell/Citgo Refinery (LCR) revamp/expansion mega project in the Houston area was used as the primary source of data. This jobsite is already pioneering wireless data communication to track percent completion of major work packages as well as to perform basic material management functions.

Other unique features of the Lyondell/Citgo Refinery expansion project include:

- \$1.2 billion dollar cost
- 100 Subcontractors
- 9 million work hours
- 2 general contractors (H.B. Zachry and S&B Engineer and Constructors)
- 4 engineering companies (Bechtel, Foster-Wheeler, Kellogg, Pritchard)
- 2 merging owners (Lyondell and Citgo)

- 4 grass-roots projects
- 2 revamp projects

1.3 Methodology

The LCR revamp/expansion "mega" project in the Houston area was targeted for visits with the purpose of eliciting and articulating information needs as well as to assess the impact that the typical construction environment may have on the effectiveness of the wireless data communication technologies. These visits served to address the human factors associated with using wireless applications by jobsite personnel. Key questions to be addressed were:

- Q1. What is the potential of existing wireless technology to address the information needs of today's construction jobsite?
- Q2. What is the future potential of emerging wireless technologies to address the information needs of tomorrow's construction jobsite?

After the data reconnaissance visit to the LCR projects, a series of tables were developed to articulate the information needs that were found to exist there. After these tables were produced, they were distributed to the CII research team for validation and revision. These tables define specific parameters about the different types of information needs and are contained in Chapter 3.

Concurrent to the articulation of information needs, a survey of wireless technology that is available off-the-shelf was conducted. This survey examined several different formats of wireless communication from several different manufacturers. A series of tables were produced that articulate feature and performance parameters for each product. These tables form the basis of Chapter 5.

Once the information needs at a construction jobsite and the wireless products that are currently available were identified, a methodology for determining an appropriate wireless product for a given set of information needs was developed. There are two hypothetical case studies that are included to illustrate the use of the methodology. This methodology and the hypothetical examples are the basis of Chapter 6.

1.4 Survey of the Document

This document contains seven chapters. Chapter 2 examines some of the information needs in industries other than construction and discusses the four formats of wireless communication considered. Chapter 3 reviews the data reconnaissance visit to the LCR in Houston, Texas. The chapter then articulates, in ten categories, the information needs that were found at the LCR project. These two chapters address the first objective of this study, i.e., to perform a survey of the information needs at a jobsite.

Chapter 4 is a Primer on wireless communication technology. It introduces fundamental and advanced wireless communication concepts. Chapter 5 contains a survey of different wireless communication products that are available on the market today. These two chapters address the second objective of this study, i.e., to perform a survey of wireless communications technology.

Chapter 6 presents a methodology for using the information in Chapters 2 through 5. Such methodology can be utilized by a company to help it determine if a wireless communication system can meet its own information needs. This chapter addresses the third objective of this study, i.e., to assess how well wireless communication systems can fulfill the information needs of the construction jobsite.

1.5 ReadMe.First

This section should be read before the rest of the document. This document has limitations and it is the intent of the authors to make these limitations known up front.

First, the purpose of this document is to develop rudimentary "in-house" (i.e., contractor, owner, etc.) expertise in wireless technology. This document provides enough information to allow one to become knowledgeable enough to investigate wireless communications. It is not intended to make someone a wireless communications expert.

Second, this document is a "first step" in deploying wireless communications at the jobsite. In spite of reading and understanding this document, it may still be necessary for a company considering wireless technology to consult with an expert in the wireless communications field.

Third, it is recommended that this document be read cover to cover. No section in this document should be taken out of the context of the rest of the document. However, the reader

desiring just an introduction as to how wireless systems could benefit their company and how they can be used in the industry should concentrate their attention on chapters 1,2,3, and 7; and the reader who is interested in actually implementing a wireless system should focus on all chapters.

Fourth, this document represents a framework that can be used to incorporate wireless communication technology into the jobsite. It does not represent a "canned" solution that can be used by any construction firm on any construction site.

Finally, the technical solutions and products that are identified in Chapter 5 will become dated as new developments are introduced into the market place. However, the framework presented in Chapter 3 and the methodology discussed in Chapter 6 will remain applicable for at least the short to medium term.

1.6 The CII Research Team

CII's Research Team #136 included the following individuals:

- Alan Waldbusser, Research Team Chairman, TPA, Inc.
- Mikkell Hansen, Texaco Inc.
- Joseph St. Julien, H. B. Zachry, Co.
- John Bennett, H. B. Zachry, Co.
- Dr. William Stone, NIST

There were two Virginia Tech faculty members on the research team, Dr. Jesus M. de la Garza, Associate Professor in the 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. Jason Gagnon was a Virginia Tech Graduate Student in Construction Engineering and Management who also worked on this project. Mr Gagnon wrote his Master's of Civil Engineering Thesis in conjunction with this research project.

2. Articulation of Information Needs

2.1 Introduction

This chapter has three primary goals, namely, to discuss cost/benefit issues, to examine other industries' information flow models, and to examine and define ways in which data can be transmitted wirelessly.

2.2 Cost Versus Benefit of Wireless Technology

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 technology. 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.

Figure 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 to send to the trailer at 8:00 AM. The value of this information at 8:00 AM is V_1 . If the foreman had access to a wireless information system, he could immediately download that information to the trailer at a cost of C_1 . 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 V_2 , because of the nine hour time delay. The cost of delivering the information has also decreased, as shown by C_2 . 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 $\text{ValueAdded1} > \text{ValueAdded2}$?

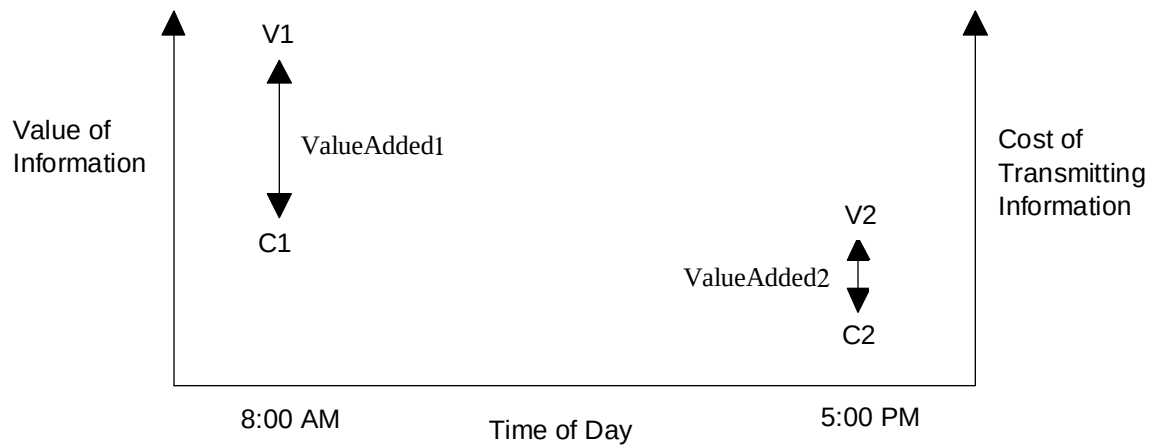


Figure 1 Cost-Benefit Example 1

The next example examines the productivity that is lost if the foreman needs to leave the field to deliver information to the trailer. Figure 2 is set up the same way as Figure 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 AM, at a cost of C1. 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 AM. The value of the information has not changed much between V1 and V2. However, when the foreman leaves the field, his crew's productivity will decrease and the cost of transmitting the information increases from C1 to C2. This is another way that a company might want to approach their analysis of wireless communication. The question again is: is $\text{ValueAdded1} > \text{ValueAdded2}$?

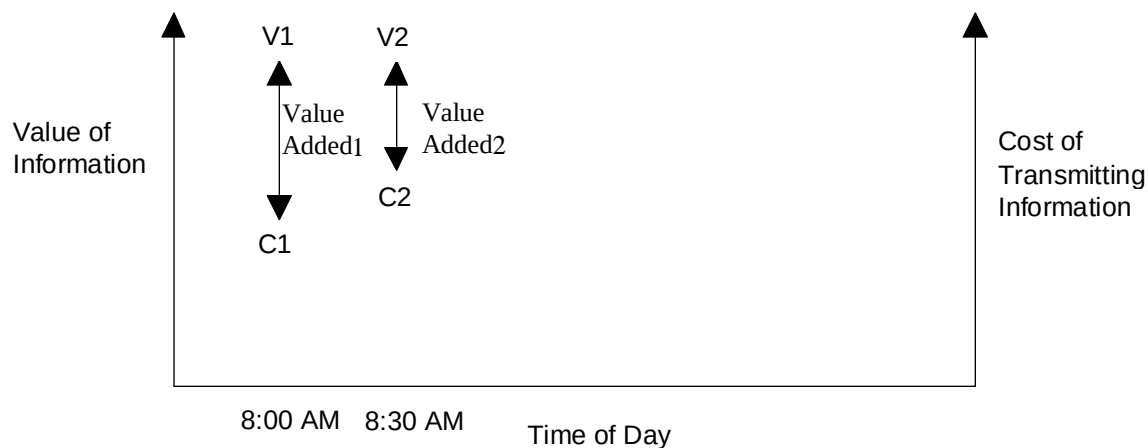


Figure 2 Cost-Benefit Example 2

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 data communications technology than without it. Section 6.3 of this report provides a hypothetical example which includes one-time 1996-based hardware expenses. Keep in mind, however, that on-going costs likely outweigh initial one-time costs.

2.3 Other Industries' Information Models

There are a few industries that have already incorporated communication systems into their respective work places. This section examines examples of the information models in the manufacturing, trucking, and package delivering industries. The construction industry faces different challenges from those that are faced by these and other industries. However, generic information concepts can be learned by studying them.

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 requires at his work station might be similar to the types of information that a construction foreman requires while working in the field.

The industries that ship goods from one place to another are similar to the construction industry in their dynamic nature--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.

In summary, the construction industry can benefit from studying what has worked to improve the flow of information in other sectors and by modifying and applying these ideas to itself.

2.3.1 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 line is operating at full speed, the factory can produce over ninety trucks in one hour. The plant has over 2,000 employees.

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 custom made. Volvo / GM offers a few basic body designs with many different variations, but all of the trucks that they produce start with the same chassis. When a new truck is started on the line, there are a set of paper specifications and drawings that are attached to it and that travel with it throughout the line. This set of specifications show what variations to the basic design need to be made. The foreman at each station checks 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 specifications which are sent to the plant floor for assembly. There are many different systems in a given truck that can be modified to meet individual customer's needs. These include the engine size, cab type, the color

of the cab, type of radio, etc. Once a customer places an order, it goes to a CAD team that produces a complete CAD model for each truck. The model is the basis for the paper drawings that travel with the truck while it is on the production line.

Volvo / GM is planning to install computer terminals at each of the stations on the assembly line. Since, these terminals will be hardwired into the plant's computer system, the foreman of each crew will be able to look at the CAD model or portions of it for any given truck. This will 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 will be able to access the information that his crew needs faster and more efficiently than with the current paper-based system. The foremen on the floor will have "read-only" capabilities to view the drawings. However, there are plans for the foreman to be able to record any changes, modifications or concerns about a given vehicle while it is on the line. These changes, modifications or concerns will be addressed after the vehicle has left the line. This is to prevent the production 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 if the information were 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 company could impose the same "read-only" requirement.

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 needs attention, they do 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 is 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.

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

Federal Express and 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 companies address in order to insure the quality of their service. Both of these companies 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.

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 the truck. From this point forward, both the customer and company can track the package. 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 as he/she drives to the next pickup/delivery location.

UPS uses its own satellite for information communication. They have a global information network of which the satellite is an important part. 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 their information flow needs of the "last mile".

2.3.3 The Trucking Industry

There is a move in the trucking industry to incorporate the Global Positioning System (GPS) and communication satellites. The trucking industry is very dynamic--most of its resources are in motion at any given point in time.

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 telephones. First, there are still many areas in the country that do not have cellular service provided. Second, a dispatcher is still dependent on the 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 [WHI96].

Trucking companies are considering GPS and other satellite dependent communication systems to improve their communication. There are two primary information needs in the trucking industry. 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 GPS and satellite communication into its fleet is Day & Night Transportation Services, based in Noblesville, IN. They have outfitted about half of their trucking fleet with GPS and satellite communication capabilities. Using GPS, dispatchers at Day & Night's headquarters can locate where their trucks are at any point in time, anywhere in the United States. 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.

Satellite communications also play a part in the Day & Night's 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. Day & Night uses two different communication networks 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 the 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 delivery 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. 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.

2.4 Information Needs Introduction

The tables with the actual information needs based on the LCR data reconnaissance visit are presented in Chapter 3. This section will explain the headings utilized in such tables. Table 1 is an example.

Table 1 Information Needs Charts Headings

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

- ◇ **Information Subcategory** - This identifies specific types of information that are needed at the jobsite.
- ◇ **Explanation** - This gives a brief definition of 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 compressed 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 not a 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-way 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** - For each subcategory, a transmission data rate will be determined. It will be based on the amount of information to be transmitted and the allowable delay. The following formula was used to determine transmission 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 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 transmission data rate would be:

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

$$\text{Data Rate} = 0.683 \text{ kbps (Kilobits per Second)}$$

Table 2 shows all of the data rates in kbps for the three different file sizes and for the four different delay ratings.

Table 2 Data Rates (in kbps) Based on File Size and Delay Ratings

File Size	File Size in kilobytes	Delay Rating			
		< 10 mins.	< 1 min.	< .1 min.	<.01 min.
Small	< 5	.0683	.683	6.83	68.3
Medium	>5, <100	1.365	13.65	136.5	1365
Large	>100, <1000	13.65	136.5	1365	13650

2.5 Formats of Wireless Communication

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

- Live Voice
- Live Video
- Batched Data Files
- Live Data Transfer, or “Real-Time” Data (Future Trends category only)

2.5.1 Live Voice Communication

Live voice communication allows 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. The walkie-talkie is an example of a live voice wireless communication device.

There are some drawbacks to voice only communication. 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. In other words, a company that might invest only in voice communication might still find its foreman, or other personnel, needing to leave the field to communicate with the personnel in the trailer.

2.5.2 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. 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. Alternatives for live video include a mobile camera that is operated by a person or a camera that is mounted in a fixed position on the jobsite. 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.

2.5.3 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 examines 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 2.4 defined file sizes. It should be understood that the divisions of small, medium and large were chosen in the context of wireless technology. Figure 3 is a log-log graph which examines how much time is required to transfer files of different sizes given different transmission data rates of wireless communication systems under ideal conditions.

Batched file transfer also includes direct access to the contractor's computer network from the field. Payroll, costing, and scheduling applications are ideal candidates for a batched wireless approach. Two of the biggest advantages to giving a foreman or superintendent access to applications on the network are that they prevent duplication of work and provide more up-to-date information.

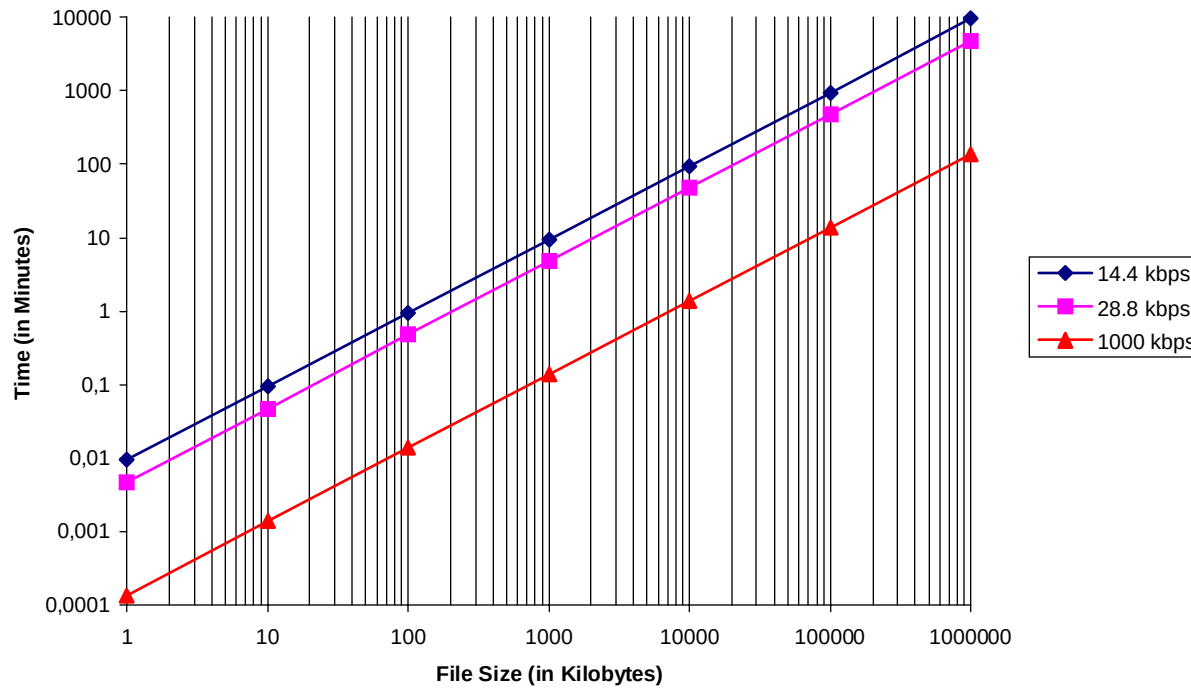


Figure 3 Comparison of Different Rates of Data Transfer Using Equation 1

2.5.4 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 are information needs that are discussed in the category about Future Trends that might require a live stream of data to be transmitted. This type of transfer requires that both transmitter and receiver be capable of handling significant amounts of information with no or extremely minimal latency.

3. The Lyondell-Citgo Data Reconnaissance Visit

3.1 Introduction

A data reconnaissance visit to the LCR project took place in March, 1996 to distribute a questionnaire and to conduct interviews with field personnel. This chapter examines the processes and methodologies that were used during the gathering and distillation of information from this project. The core of this chapter consists of jobsite information needs organized into the following ten categories: a) Requests for Information; b) Materials Management; c) Equipment Management; d) Cost Management; e) Schedule and Means & Methods; f) Jobsite Record Keeping; g) Submittals; h) Safety; i) QC/QA; and k) Future Trends. Each category was analyzed in terms of its appropriateness to take advantage of wireless technology. The four formats considered to transmit information wirelessly were: a) live voice; b) live video; c) batched data; and d) live data.

3.2 The Lyondell-Citgo Refinery Project Visit

The LCR project was chosen by the CII Research Team as the primary source of information for this study. The LCR project is both a renovation and expansion to a crude oil refinery in the Houston area. The research team chose this site for several reasons. First, H. B. Zachry was a prime contractor at the LCR and is a member of CII with two representatives on this CII Research Team. Both of these representatives were also assigned to the LCR project. Additionally, H. B. Zachry was already using wireless communication technology on the project.

Second, the LCR was chosen for its complexities as a construction project. The construction was taking place within the confines of an operating refinery. 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, 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 reasons, the LCR site would be a good indicator of some of the conditions that might affect the performance of wireless technology.

3.2.1 The LCR - Overview

The 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 design, management and construction contractors to build this project. There were five main units (areas of new and revamp construction) that were divided between two prime contractors (H. B. Zachry and S&B). Additionally, both of the prime contractors maintained significant off-site operations to support their efforts on-site.

LCR maintained a Project Management Team (PMT) that was on site. The new and revamped facilities were primarily designed by Bechtel, who also played a major role on the PMT in the administration of the construction. Most of the rest of the PMT, that the team met, were employees of Citgo.

The team spent time at all three of the H. B. Zachry units as well as their off-site office. The team spent time at the S & B off-site office 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.

3.2.2 The LCR Questionnaires

There were essentially three categories of questions contained in the questionnaires are as follows:

- 1.) Background and Categorization Questions: These questions were used to determine the nature of the respondent’s background, their role in the current project and their overall background in the construction industry. They were also designed to ascertain any previous exposure that the respondents had had with wireless technology and applications. These questions were designed to help qualify the answers to subsequent questions.

- 2.) Data Elicitation: There were three sections of the questionnaire for data elicitation. The first was used to determine areas that could be improved by a better flow of information. The second was used to determine what data needs could be met by different methods of wireless data transmission. The third 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 suggestions not covered specifically in the other questions.

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. The team stated that the questionnaire was to assess information needs between the field and the job trailer. The data collection 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. Overall, the reaction to the questionnaire was positive.

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 had left.

3.2.3 The LCR Interviews

There were a series of interviews that were conducted after the respondents had an opportunity to look at or complete the questionnaire. The interviews were very informal. The data collection team wanted to generate as much open and interactive dialogue as possible. The interviews ranged in participation from one person to six people. 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. 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. The team believed that more beneficial information was coming from the interviews than from the questionnaires. The reactions of all those interviewed were primarily positive. 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 all participants 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.

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

3.3 Jobsite Information Needs Categories

Upon completion of the site visit to the LCR projects, the information gathered was compiled and classified into eight information categories. This number was subsequently expanded to ten. The information was further divided into subcategories. Every category had at least two subcategories, most had more. Table 3 provides a general classification of jobsite information needs with the top row providing links to more detailed tables.

Table 3 Classification of Jobsite Information Needs

Request for Information	Materials Management	Equipment Management	Cost Management	Schedule and Means & Methods	Jobsite Record Keeping	Submittals	Safety	QC / QA	Future Trends
Table 4	Table 5	Table 6	Table 7	Table 8	Table 9	Table 10	Table 11	Table 12	Table 13
Design Intent and Clarification	Access to Material Management	Equipment Location	Budget	Schedule Updates	Recording Time Sheets	Test Results	Accident Reporting	Initiate Inspections	Positioning Data
Subcontractor Information	Material Location	Fuel Monitoring	Material Cost Accounting	Delay Recording	Progress Reporting	Revisions to Submittals	Reporting Violations	Report QC/QA Problems	Sensory Data
Contract Specifications	Material Order Status		Equipment Cost Accounting	As - Built Records	Exception Reporting			Report Inspection Results	
Contract Drawings	Request Materials to Site			Productivity Information	Visitor's Log				
Work Package Information	Place Material Orders								
Means and Methods									
Implementation Problems									

Summary of Request for Information. Referring to the summary section of Table 4, 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.

Summary of Materials Management. Referring to the summary section of Table 5, it can be seen that for most of the subcategories live voice was considered a somewhat important format of information transfer. Alternately, live video was not considered important. 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.

Summary of Equipment Management. Referring to Table 6, 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.

Summary of Cost Management: Referring to the summary section of Table 7, it can be seen that live voice was seen with mixed reactions 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 small batched transfers is .68 kbps, which is low. For medium and large batched files, time is not a factor.

Table 4 Information Category: Requests For Information

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
			Medium	< 1	4	D	13.65
			Large	<10	3	D	13.65
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
			Medium	NF	1	D	>1
			Large	NF	1	D	> 1
3.) Contract Specification	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
			Medium	<1	2	D	13.65
			Large	NF	1	D	>1
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
			Medium	<1	4	D	13.65
			Large	<10	4	D	13.65
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
			Medium	< 10	3	D	1.37
			Large	NF	1	D	> 1

Table 4 Information Category: Requests For Information (Cont'd)

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
			Medium	<1	4	D	13.65
			Large	<10	3	D	13.65
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
				Average (in Mins)	Average		Defining Value (kbps)
	SUMMARY FOR CATEGORY	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

Table 5 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
			Medium	< 1	3	D	13.65
			Large	NF	1	D	> 1
2.) Material Location	To allow field personnel to find the location of any given piece of material that is required.	Voice		< .01	4	D	8 - 32
		Video		< .01	1	SF	128 - 10,000
		Batched Data	Small	< 1	5	D	0.68
			Medium	< 1	3	D	13.65
			Large	NF	1	D	> 1
3.) Order Status	To allows personnel to find out what the status is of an item that has been ordered.	Voice		< .01	5	D	8 - 32
		Video		< .01	1	SF	128 - 10,000
		Batched Data	Small	< 1	4	D	0.68
			Medium	< 10	2	D	1.37
			Large	NF	1	D	> 1

Table 5 Information Category: Materials Management (Cont'd)

Information Subcategory	Explanation	Formats of Info. Transfer	Type	Delay (mins)	Importance	Simp. / Dup	Data Rate (in kbps)	
4.) Request Materials to be Brought to the Site	When material is needed for installation, site personnel can order from the field.	Voice		< .01	5	D	8 - 32	
		Video		< .01	1	SF	128 - 10,000	
		Batched Data	Small	< 1	1	D	0.68	
			Medium	< 10	1	D	1.37	
			Large	NF	1	D	> 1	
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		< .01	5	D	8 - 32	
		Video		< .01	1	SF	128 - 10,000	
		Batched Data	Small	< 1	4	D	0.68	
			Medium	< 1	1	D	13.65	
			Large	NF	1	D	> 1	
				Average (in Mins)	Average		Defining Value (kbps)	
	SUMMARY FOR CATEGORY		Voice		< .01		4.60	8 - 32
			Video		< .01		1.00	128 - 10,000
			Batched Data	Small	< 1		3.80	0.68
				Medium	< 4.6		2.00	13.65
				Large	NF		1.00	> 1

Table 6 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	
			Medium	< 10	3	D	1.37	
			Large	NF	1	D	> 1	
2.)Fuel Monitoring and Refueling	To monitor fuel status and facilitate the routing of the fuel and oil trucks.	Voice		< .01	5	D	8 - 32	
		Video		< .01	1	SF	128 - 10,000	
		Batched Data	Small	< 1	4	D	0.68	
			Medium	< 10	2	D	1.37	
			Large	NF	1	D	> 1	
				Average (in Mins)	Average		Defining Value (kbps)	
	SUMMARY FOR CATEGORY		Voice		< .01		5.00	8 - 32
			Video		< .01		1.00	128 - 10,000
			Batched Data	Small	< 1		4.00	0.68
				Medium	< 10		2.50	1.37
				Large	NF		1.00	> 1

Table 7 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
			Medium	NF	1	D	> 1
			Large	NF	1	D	> 1
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
				Average (in Mins)	Average		Defining Value (kbps)
SUMMARY FOR CATEGORY		Voice		< .01	2.67		8 - 32
		Video		< .01	1.00		128 - 10,000
		Batched Data	Small	< 1	4.00		0.68
			Medium	NF	1.00		> 1
			Large	NF	1.00		> 1

Summary of Schedule and Means and Methods. Referring to the summary section of Table 8, it can be seen that live voice was considered a somewhat important format of information transfer. Live video was considered unimportant. Small batched files were considered a very important type and 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.

Summary of Jobsite Record Keeping. Referring to the summary section of Table 9, 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 and 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.

Summary of Submittals. Referring to the summary section of Table 10, 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. The maximum data rate required for any of the batched transfers is 13.65 kbps.

Table 8 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	< 1	5	D	0.68
			Medium	NF	1	D	> 1
			Large	NF	1	D	> 1
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	< 1	5	D	0.68
			Medium	< 1	3	D	13.65
			Large	NF	1	D	> 1
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	< 1	5	D	0.68
			Medium	NF	1	D	> 1
			Large	NF	1	D	> 1
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	< 1	5	D	0.68
			Medium	NF	1	D	> 1
			Large	NF	1	D	> 1
				Average (in Mins)	Average	Defining Value (kbps)	
SUMMARY FOR CATEGORY		Voice		< .01	4.00	8 - 32	
		Video		< .01	1.00	128 - 10,000	
		Batched Data	Small	< 1	5.00	0.68	
			Medium	< 1	1.25	13.65	
			Large	NF	1.00	> 1	

Table 9 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	
			Medium	NF	1	D	> 1	
			Large	NF	1	D	> 1	
2.) Progress Reporting	Field personnel would be able to submit progress reports from the field.	Voice		< .01	2	D	8 - 32	
		Video		< .01	1	SF	128 - 10,000	
		Batched Data	Small	< 1	4	D	0.68	
			Medium	< 1	2	D	13.65	
			Large	NF	1	D	>1	
3.) Exception / Incident Reporting	To be able to report work that was not installed according to plan.	Voice		< .01	2	D	8 - 32	
		Video		< .01	1	SF	128 - 10,000	
		Batched Data	Small	< 1	5	D	0.68	
			Medium	< 10	2	D	1.37	
			Large	NF	1	D	>1	
4.) Visitor's Log	To record visits to site by owner, engineer, safety inspector, contractors representative or other persons.	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	
				Average (in Mins)	Average		Defining Value (kbps)	
SUMMARY FOR CATEGORY		Voice		< .01	2.25		8 - 32	
		Video		< .01	1.00		128 - 10,000	
		Batched Data	Small	< 1	4.33		0.68	
			Medium	< 5.5	1.67		13.65	
			Large	NF	1.00		>1	

Table 10 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
			Medium	< 10	3	D	1.37
			Large	NF	1	D	> 1
2.) Revisions to Previous Submittals	To send any changes to any previous submittals that might have been changed in the field during progress.	Voice		< .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
				Average (in Mins)	Average		Defining Value (kbps)
SUMMARY FOR CATEGORY		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

Summary of Safety. Referring to the summary section of Table 11, 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. Large files were considered to be unimportant. The maximum data rate required for any of the batched transfers is 13.65 kbps.

Summary of Quality Control / Quality Assurance. Referring to the summary section of Table 12, 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 files were considered unimportant. The medium batched files required the maximum data rate of 13.65 kbps.

Summary of Future Trends. 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 was available. By referring to Table 13 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.

Table 11 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	6.83
			Medium	< 1	2	D	13.65
			Large	NF	1	D	> 1
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	6.83
			Medium	< 1	2	D	13.65
			Large	NF	1	D	> 1
				Average (in Mins)	Average		Defining Value (kbps)
SUMMARY FOR CATEGORY		Voice		< .01	5.00		8 - 32
		Video		< .01	1.00		128 - 10,000
		Batched Data	Small	< .1	2.00		6.83
			Medium	< 1	2.00		13.65
			Large	NF	1.00		> 1