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16. Abstract

Texas Department of Transportation (TxDOT) engineers are responsible for the design, evaluation, and implementation of Intelligent Transportation System (ITS) solutions across the entire state. These installations occur with vast differences in requirements, expectations, and constraints. Many deployments require some type of communication system to complete the installation.

This report details the development of a reference guidebook and training workshop for TxDOT engineers. The purpose of these materials is to:

- establish a fundamental level of understanding of wireline communication concepts and technologies,
- convey and explain a comprehensive process for assessing communication needs for ITS deployments, and
- create a set of workshop materials for future training program opportunities.

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DEVELOPMENT OF A WIRELINE COMMUNICATIONS DESIGN GUIDEBOOK FOR INTELLIGENT TRANSPORTATION SYSTEMS

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DISCLAIMER

This research was performed in cooperation with the Texas Department of Transportation (TxDOT) and the Federal Highway Administration (FHWA). The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of FHWA or TxDOT. This report does not constitute a standard, specification, or regulation. The researcher in charge of the project was Robert E. Brydia.

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INTRODUCTION

BACKGROUND

The telephone was the beginning of a worldwide revolution in communications. From a single connection demonstrated in 1876 to the first telephone exchange in 1877 to the first inter-city connections in 1883, the growth of the telephone highlights the historical birth of wide area communications. Within 15 years of its invention, the number of telephones in use in the United States exploded to more than five million. *1,2*). A growing system of telephone lines—primarily bare copper wire—made possible these long-distance connections. The greatest limitation to the telephone's usefulness was that a wire could only carry one conversation at a time. Telephone exchanges were constructed to handle the switching of calls and manually connect one wire to another to complete the voice circuit (*3,4*). In 1927, the first demonstration of video transmission along the telephone network took place between Washington DC and New York City (*5*).

In 1941, the first segment of the national telephone network using coaxial cable went into service. Coaxial cable was a vast improvement over the existing copper cable and was able to carry more calls at a lower cost.*(5)* Trans-Atlantic telephone service via telephone cable was initiated in 1956. Previously, calls had been transmitted across the ocean via radio waves. The initial trans-Atlantic cable could carry 36 simultaneous calls.

In 1983, AT&T laid the first fiber optic cable on the national long-distance network. Today, the domestic long-distance network is nearly 98 percent fiber optic. A single strand of fiber carries thousands of simultaneous calls at a fraction of the cost of copper cabling *(5)*.

From these modest beginnings, the era of communications grew to encompass all aspects of our lives. From telephone calls to cable television to Internet connectivity, achieving stable and reliable communications is a critical component of providing high-quality services.

In much the same way, intelligent transportation systems (ITS) rely on these same communication services to collect information and provide services. From roadway sensors to remote video cameras to dynamic message signs (DMS) and Internet traffic sites, communications are a critical component of the solutions deployed by the Texas Department of Transportation (TxDOT).

Today, TxDOT engineers are responsible for the design, evaluation, and implementation of ITS solutions across the entire state. These installations occur with vast differences in requirements, expectations, and constraints. Over time, as the available communication options have expanded, it has become more difficult to have a comprehensive overview of the basics as well as a thorough understanding of the pros and cons of the different technologies.

GOALS OF PROJECT

In order to improve the communication systems designed and implemented by TxDOT, the department contracted for a one-year research project with the Texas Transportation Institute (TTI). There were three goals of the project:

- Determine the fundamental concepts of communications knowledge necessary for all employees utilizing these technologies as part of their ITS solutions.
- Design an evaluation process for typical communication technologies used in ITS deployments to ensure TxDOT can design and implement practical, cost-effective, reliable, and consistent communication systems.
- Prepare workshop materials enabling TxDOT to train their employees in both the fundamental requirements and the stepwise evaluation process for communications systems.

It is important to understand that the evaluation process should be able to support both the design of a new system or the evaluation of an existing design, as each is a task performed frequently by the target audience.

PROJECT DELIVERABLES

The results of this research project are implemented in three products, all of which will have an immediate use to TxDOT. These products are more specifically described as follows:

1. *A formal evaluation process* to analyze communication system design choices and provide guidance on selecting the best choice within the existing constraints. This final project report details this deliverable, which is also an integral component of the participant’s notebook and the workshop materials.
2. *A design guidebook* that details the fundamental concepts of technologies utilized for ITS communications as well as the evaluation process, which is illustrated through

the use of case studies. The design guidebook serves as the participant's notebook for the workshop materials identified in deliverable three.

3. *Materials to support a half-day workshop* that teaches the main principles of the guidebook and evaluation process. These materials include an instructor's notebook with PowerPoint slides on a CD-ROM. The use of electronic format for this deliverable enables TxDOT to teach the course at any future time at needed locations, as well as making it available on internal websites.

FORMAT OF THIS REPORT

The deliverables for this project contain the full set of materials developed during the course of this research. The function of this report is not to duplicate those resources, but to highlight how TTI developed and assembled the information. This report conveys in the following chapters the information:

- discussion of the fundamental aspects of communications and what the workshop materials include,
- listing of the typical ITS communication technologies and their application to the ITS arena,
- development of evaluation methodology and its application in ITS communications, and
- development and format of the instructor's materials for the workshop.

COMMUNICATION FUNDAMENTALS

SELECTION OF TOPICS

Communications is a broad field. Even books covering just the fundamentals can run hundreds of pages. A careful review of many sources (*6*,*7*,*8*,*9*,*10*,*11*,*12*) revealed, however, that conveying the details of communications required the development of a great deal of material. It is important to remember, however, that the goal of the workshop and project was not to create communication engineers, but rather to assist ITS engineers in their tasks dealing with communications. In fact, the typical workshop audience member is a TxDOT employee with some level of overview or responsibility for ITS, but little to no background in the area of communications. As such, the important concepts are items such as costs, constraints, typical deployments, and interoperability, not detailed technical discussions pertaining to theory or electrical and optical signaling techniques.

The following sections present the broad topics described in the guidebook and workshop materials. The research team based their selection of topics on a review of selected documents, including:

- textbooks,
- federal publications,
- web site repositories of communications information, and
- feedback from the project panel on important topics.

The researchers chose a bottom-up approach to teaching communication topics. By first introducing the physical media, then layering in the protocols that run on these wires, researchers developed a selection of technologies applicable to the ITS industry. Guidebook discussion covered each technology in a standardized format and compared it with the other technologies across significant areas of consideration, such as bandwidth and speed. Researchers felt this teaching method was the best way to develop fundamental knowledge and ensure that people across TxDOT had the same fundamental understanding of communication concepts.

Information

The world around us contains all types of information. Temperature, time, sound, color, noise, and even pollen levels are just a few of the types of information we encounter on a daily basis. The guidebook materials discuss information and how it is related in either an analog or digital format.

Transfer of Information

The core concept of communications is transferring information from one location to another. It doesn’t matter if that information is expressed in analog or digital formats. The important concepts in this section of the guidebook materials are the concept of bits (the smallest unit of information) and the assembly of bits into larger units of information.

Bandwidth

In communications, the term ‘bandwidth’ refers to how much data can be transmitted in a certain amount of time. In essence, bandwidth is a measure of the size of the communications pipe. The guidebook introduces bandwidth at an early stage as it is a fundamental concept in communications and especially in selecting an appropriate technology for ITS implementations.

Analog and Digital

Analog and digital communications, while both doing the same thing (transferring information), accomplish it in very different mechanisms. The thrust of the material in the guidebook is on digital communications, but the fundamental concepts explain analog, digital, and the relationship between the two.

Wireline Media

Wireline communications require some type of physical cable, or medium, to move information from one point to another. In the early days of networking and computers, this medium was limited to a metallic wire. Some of the original communications were done using a bare, or open, wire with no insulation. Today, those types of installations are mostly non-existent.

While metallic cables still make up a large amount of the physical media used in communications, optical cable, typically called fiber, is a popular alternative. The guidebook discusses twisted-pair cabling, coaxial cabling, and fiber optic cabling. The discussions describe typical uses, different types within each type of wiring, and typical connectors, and use illustrations to ensure a fundamental knowledge of wireline media.

Protocols

In essence, a protocol is a standardized method of taking any type of information and breaking it up into discrete units that can be sent along any type of media. Although it sounds somewhat complicated, a protocol is really nothing more than a set of rules for handling and exchanging information. In order to ensure that readers understand this basic concept, the guidebook materials spend a significant level of detail developing the fundamental aspects of a protocol through analogies to a telephone call and describing the characteristics common to all protocols.

This guidebook also explains the concept of protocol stacking via internationally known standard implementation of the open systems interconnection (OSI) seven-layer model. It is important to understand that protocols work cooperatively to send and receive information and that there are numerous levels of protocols at work for each information transfer.

Common ITS Protocols

The guidebook introduces the protocols that ITS deployments most often use, including:

- Serial (RS-232, RS-422, and RS-485)
- Digital Subscriber Line
- Frame Relay
- Asynchronous Transfer Mode (ATM)
- Synchronous Optical Network (SONET)
- Transmission Control Protocol / Internet Protocol (TCP/IP)
- Ethernet

Each protocol discussion utilizes a standard format that describes briefly how it works and the performance characteristics.

In addition to the protocols listed above, the text also describes other protocols that ITS deployment are likely to use. These protocols include:

- HTTP – Hyper Text Transfer Protocol – HTTP defines how messages are formatted and transmitted, and what actions Web servers and browsers should perform.
- FTP – File Transfer Protocol – FTP defines how to transfer files over the Internet.

- SOAP – Simple Object Access Protocol – a messaging protocol based on the eXtensible Markup Language (XML) that is used to encode information into a format known as a Web service.
- SNMP – Simple Network Management Protocol – a set of protocols used to remotely manage networks and devices.
- NTP – Network Time Protocol – a protocol used to ensure accurate synchronization of clock times in a network of computers and devices.
- SMTP – Simple Mail Transfer Protocol – a protocol for sending electronic mail messages between servers.
- NTCIP – National Transportation Communications for ITS Protocol – a family of standards that was created to address the needs of both current and next-generation transportation communication systems.

Topologies

Topology refers to the arrangement of computers or devices inside a network. Topologies can be either physical or logical. A physical topology looks at the actual location and connections at various devices. In contrast, a logical topology is the way that data pass through a network from device to device without concern for how they are physically connected or where they are located.

The guidebook materials describe and illustrate typical topologies as they are an important concept in understanding communication systems. Topologies covered by the workshop materials include:

- point-to-point,
- star,
- ring,
- bus, and
- hybrid.

Typical Communications Equipment

While this course is not meant to describe in detail the communications equipment used to construct ITS solutions, the course material would be incomplete without covering some of the basic devices and their differences. The guidebook details information on:

- modems,
- hubs,
- switches, and
- routers.

Addressing Systems

The use of addressing in communications is an elemental concept of how information gets from one point to another in any communications system. Because addressing schemes can differ by protocol, they are not covered in detail in the guidebook. Rather, the materials simply introduce the concept and discuss how it is used in support of all communication systems.

Architectures

One of the concepts commonly used in ITS projects is that of an architecture. An architecture is different than the topology, which simply describes the arrangement of devices in the network. An architecture is more abstract, focusing on the relationship of all the components that comprise the ITS solution. The guidebook introduces the national ITS architecture and briefly describes its major components, since it is likely that ITS engineers have been or will be exposed to this concept.

Special Topics

There are numerous topics within the area of communications that could be covered in a book by themselves. However, while that level of detail is beyond the scope of the workshop materials, introducing these special topics gives a basic understanding and awareness to TxDOT employees. The topics introduced in this section of the guidebook include:

- spanning tree protocol,
- tunneling,
- video encoding,

- environmentally hardened equipment, and
- security.

ITS COMMUNICATION TECHNOLOGIES

TECHNOLOGY CHOICES

In today's marketplace for ITS communications, the choice of a protocol and in some cases a type of wiring, results in a technology choice. While there are dozens of communication technologies that could be implemented, typical ITS deployments utilize one of several common technologies. The guidebook covers the following nine technology choices common in ITS deployments.

- Serial (RS-232, RS-422, and RS-485)
- Plain Old Telephone System (POTS)
- Integrated Services Digital Network (ISDN)
- Digital Subscriber Line (DSL)
- Cable Modem
- T1 / T3 Services
- Asynchronous Transfer Mode (ATM)
- Synchronous Optical Network (SONET)
- Ethernet

Chapter 4 of the guidebook is devoted to explaining and understanding each of the technology choices. Within each section pertaining to a specific technology choice, a standardized format is used that details the following:

- introduction,
- history,
- capabilities,
- typical deployment methodology,
- considerations for use,
- costs, and
- supported protocols.

CROSSCUTTING TABULATIONS OF TECHNOLOGY CHOICES

Perhaps the most important outcome of the information in Chapter 4 of the guidebook material is learning how to quickly compare the technologies with regard to a critical characteristic. While each technology choice has dozens of individual characteristics, items such as bandwidth, cost, and distance could have a major impact on the appropriate choices for any given deployment situation. The guidebook contains tabulations of the following characteristics:

- wiring,
- bandwidth,
- typical deployment method,
- distance, and
- cost.

Wiring

One of the fundamental concepts of this guidebook is that there are limited wiring choices available to implement the current technology choices. Table 1 shows the wiring choices that each of the various technologies supports.

Table 1. Wiring Supported by Technology Choices.

Technology	Wire Type
Serial	Twisted Pair (1-2 pairs plus ground)
POTS	Twisted Pair
ISDN	Twisted Pair
DSL	Twisted Pair
Cable Modem	Coaxial Cable
T1/T3	Twisted Pair, Fiber
ATM	Twisted Pair, Fiber
Ethernet	Coaxial Cable (seldom used), Twisted Pair, Fiber
SONET	Fiber

Bandwidth

Bandwidth is a parameter that could reduce the available options quickly for any deployment, especially those utilizing video. Table 2 shows the nine technology choices discussed in this chapter and details the bandwidth for each choice. The table shows both a theoretical and typical or usable bandwidth as many technologies have overhead or constraints that limit the availability of the full theoretical bandwidth. An additional note is warranted in terms of the network topology, as some topologies make more use of shared bandwidth than others.

Table 2. Bandwidth for Technology Choices.

Technology	**Bandwidth**			
	Theoretical		**Typical (Usable)**	
Serial	Up to 115.2 Kbps		19.2 Kbps	
POTS	56 Kbps		40 – 45 Kbps	
ISDN	BRI – 128 Kbps PRI – 1.544 Mbps		BRI – 128 Kbps PRI – 1.544 Mbps	
DSL	Downstream	1.544 Mbps – 52.8 Mbps	Downstream	1 – 8 Mbps
	Upstream	128 Kbps – 4 Mbps	Upstream	128 Kbps – 1 Mbps
Cable Modem	Downstream	1 – 8 Mbps	Downstream	1 – 4 Mbps
	Upstream	128 Kbps – 4 Mbps	Upstream	128 Kbps – 1 Mbps
T1/T3	1.544 Mbps – 44.736 Mbps		1.544 Mbps – 44.736 Mbps	
ATM	1.54 Mbps to 622 Mbps		Up to 500 Mbps	
Ethernet	10 Mbps		4 – 5 Mbps	
	100 Mbps		40 – 50 Mbps	
	1000 Mbps		800 Mbps	
	10,000 Mbps		8000 Mbps	
SONET	51.84 Mbps – 39.812 Gbps		51.84 Mbps – 39.812 Gbps	

Typical Deployment Method

The communication technologies discussed in Chapter 4 of the guidebook have multiple deployment methods. While each section on an individual technology described the typical deployments and illustrated the setup, Table 3 brings this information together by tabulating it across all of the technologies. Some technologies, such as POTS, show more than one type of deployment method, indicating that there is more than one method of using the technology to provide communications for ITS deployment.

Table 3. Typical Deployment Method for Technology Choices.

Technology	Direct Connection	Internet Connection	Network
Serial	✓		
POTS	✓	✓	
ISDN	✓	✓	
DSL		✓	
Cable Modem		✓	
T1/T3	✓	✓	
ATM			✓
Ethernet			✓
SONET			✓

Typical Deployment Method

Many of the technology choices have some degree of limitation in terms of the distance over which they can be used to transmit information. In some cases, the limitation is specific to the media employed by the technology. For example, longer distances can often be achieved by using fiber instead of copper. Table 4 shows the typical distances associated with each technology choice discussed in Chapter 4 of the guidebook. As noted in the guidebook, TxDOT employees should be aware that specific vendor implementations may have longer distances than what are shown in Table 4, which are based on the approved standards.

Table 4. Distance Limitations for Technology Choices.

<table>
<tr><th>Technology</th><th>Distance Limitations</th></tr>
<tr><td>Serial</td><td>Depends on protocol:
<table>
<tr><td>RS-232</td><td>RS-422</td><td>RS-485</td></tr>
<tr><td>100 feet</td><td>4,000 feet</td><td>4,000 feet</td></tr>
</table></td></tr>
<tr><td>POTS</td><td>None</td></tr>
<tr><td>ISDN</td><td>18,000 feet from Central Office</td></tr>
<tr><td>DSL</td><td>18,000-30,000 feet, generally less than 18,000 feet</td></tr>
<tr><td>Cable Modem</td><td>Up to 75 miles maximum</td></tr>
<tr><td>T1/T3</td><td>None</td></tr>
<tr><td>ATM</td><td>Depends on physical media and speed:
<table>
<tr><td>Speed</td><td>Multi-mode Distance</td><td>Single-mode Distance</td></tr>
<tr><td>52 Mbps</td><td>3000 meters (10,000 feet)</td><td>15,000 meters (50,000 feet)</td></tr>
<tr><td>155 Mbps</td><td>1000 – 2000 meters (3000 to 6500 feet)</td><td>15,000 meters (50,000 feet)</td></tr>
<tr><td>622 Mbps</td><td>300 – 500 meters (1000 to 1600 feet)</td><td>15,000 meters (50,000 feet)</td></tr>
</table></td></tr>
<tr><td>Ethernet</td><td>Depends on physical media:
Cat 5 / 5e / 6 – up to 100 meters (328 feet)
Multi-mode fiber – up to 550 meters (1804 feet)
Single mode fiber – up to 5 km (3.1 miles)</td></tr>
<tr><td>SONET</td><td>Depends on physical media:
Multi-mode fiber – up to 550 meters (1804 feet)
Single mode fiber – up to 60 km (37.3 miles)</td></tr>
</table>

Costs

The costs of the various technology choices vary greatly, from a few dollars a month, to tens of thousands of dollars for a single piece of equipment. A general trend of course is that increased capability comes with increased costs. Table 5 identifies some of the typical costs associated with the technologies discussed in Chapter 4 of the guidebook.

Note that many of the technologies that are a service provided by another company have pricing that is per connection or endpoint. A typical application may have two endpoints (field and central office), which would result in double the costs. An exception would be if there are multiple field locations and only one office location. Either way, count the number of endpoint installations to determine the approximate costs.

It should also be noted that the costs listed in Table 5 are typical and may vary by location and provider.

Table 5. Typical Costs for Technology Choices.

Technology	**Approximate Cost**
Serial	$0
POTS	Costs (per end connection): $30/Month
ISDN	Costs (per end connection): BRI – $60 per month PRI – $600 – $100 per month
DSL	Costs (per end connection): Home User – $50 per month Business User – $80 to $100 per month
Cable Modem	Costs (per end connection): Home User – $30 to $60 per month Business User – $100 to $200 per month
T1/T3	T1 – $150 to $1000 per month T3 – $1500 to $9500 per month
ATM	$1000 and up per port
Ethernet	Depends on speed: 10 Mbps – $5 to $10 per port 100 Mbps – $100 per port 1000 Mbps – $1000 per port
SONET	Depends on speed: $5000 to $50,000 per port

EVALUATION METHODOLOGY

INTRODUCTION

After completing Chapters 1 through 4 of the guidebook, the reader should have a basic understanding of the following:

- choices in wireline media,
- concept and use of protocols, and
- an overview of the typical solutions employed in the ITS arena.

In addition, these chapters present the following important concepts related to ITS deployments:

- topologies,
- video encoding,
- information transfer rates, and
- more.

The next step is to take this fundamental knowledge base and apply it to TxDOT's typical needs. These needs consist of either designing a new system/deployment or evaluating an existing system/deployment. By providing a stepwise procedure to assess the communication needs, the decision of which technologies to consider can be significantly narrowed.

LIMITATIONS

It must be recognized that no procedure can examine all of the choices and provide a single answer of "this" technology for "that" situation. While communication is a science, building communication systems is more of an art. Multiple solutions could be built for any given scenario, but they would all have different strengths and weaknesses. The final solution of decision depends on many deployment-specific items, such as:

- cost,
- scalability,
- available expertise, and
- more.

Instead, TTI's goal of constructing these procedures for TxDOT is narrowing down the wide range of choices into a subset of "best options." ITS engineers must then utilize their individual knowledge and experience to choose a final solution for their particular deployment situation.

TERMINOLOGY CRITICAL TO METHODOLOGY

Prior to looking at the procedures, there are several terms that should be identified and discussed, as they are critical components of the procedures that follow.

Bandwidth

Bandwidth refers to the amount of information that can be transmitted in a certain amount of time and is usually expressed in bits per second. The various sections in the guidebook illustrate that each technology has a different bandwidth. In addition, Table 2 tabulates the theoretical and usable bandwidth for each technology.

In terms of a design or evaluation, the concept of bandwidth is used as a requirement. Each device has a rate at which it transmits information. This rate may be variable depending on the needs of the particular deployment. This rate is a required bandwidth. The sum of the required bandwidth, across all devices in the deployment, is a key factor in determining an appropriate communication solution.

Latency

Latency is a synonym for delay. Simply put, latency is a measure of the amount of time it takes a piece of information to get from one designated point to another. Latency is an important concept for designing communication solutions, as different applications may be sensitive to different amounts of latency. The methodology employed to determine the best subset of options allows TxDOT to adjust the latency requirements based on the particular needs of any given deployment.

Unicast and Multicast

While the guidebook materials cover the concept of topologies, another critical aspect of communications is not only how to arrange devices, but how they “talk” to other devices. The two most common design scenarios for communications are multicast and unicast.

In unicast communications, an individual device can only "talk" to another individual device; it is a point-to-point conversation. By comparison, multicast communications allow one device to "talk" to multiple other devices simultaneously.

Because unicast is a point-to-point scenario, it is not well suited to a situation where the same information has to be received at multiple locations. In fact, for video communications, this scenario may impose significant additional costs for extra equipment. However, multicast networks are more difficult to set up and maintain and may require more significant expertise to achieve stable operations. The design methodology provides TxDOT significant guidance on the best design situation (unicast or multicast) for any particular situation by asking a few questions and using accepted communication system design principles.

DATA COMMUNICATIONS

By their nature, data communications do not typically require extensive bandwidth. In fact, if no video information is being transmitted, even a basic solution such as a telephone line can transfer a significant amount of information. However, one of the primary issues related to data communications is the speed in which information is transmitted.

Speed of Transfer

Consider an example where a sensor on the roadway has to transfer information back to a central location. Furthermore, assume that the size of the information is 150 KB, or 1200 Kb. For this example, we'll assume that a phone line (POTS) is in place for the data transfer.

From Table 2, we know that a typical phone line solution transfers information at approximately 40 Kbps. Therefore, the time it takes to transfer this amount of data over the phone line will be:

$$1200\ Kb \div 40\ Kbps = 30\ seconds$$

However, if these data are needed for real-time operations, a 30-second delay may not prove a feasible solution.

Now consider the same scenario, but the communications connection has been switched to a DSL line. If the connection speed on the uploading side is relatively low, say 128 Kbps, the time to transfer the information will be:

$$1200\ Kb \div 128\ Kbps = 9.4\ seconds$$

This speed is significantly better than 30 seconds but still may not be fast enough for “real-time” purposes. However, if the upload speed of the DSL connection was a more robust 1 Mbps, the time to transfer the information would be:

$$1200\ Kb \div 1000\ Kbps = 1.2\ seconds$$

As can be seen, information transfer for data can be accomplished in multiple ways, but the speed at which it is accomplished may prove to be a critical factor in the design. Unfortunately, it is difficult, if not impossible, to capture this type of need internal to a design and evaluation process. The designer must often utilize personal knowledge and experience to produce the best solution for the given scenario.

Size of Data

Another interesting aspect of data communications is that they are often a start/stop type of communication, as opposed to video which is always on. A dynamic message sign may only have a message displayed periodically; say, once a day. Most of the time, the DMS have little to no data communication needs as no information is being exchanged.

Given that bandwidth is defined as an amount of information transferred over a set unit of time, one method of calculating the bandwidth requirements is to take the total bandwidth used during the DMS transmissions and convert it to an equivalent usage per second, the typical timeframe used for bandwidth.

Consider the following example. A DMS message is 1 KB in size and that device acknowledges a transmission with a return message of the same size. Furthermore, this transfer takes place in a total of five seconds. The equivalent bandwidth used is:

$$2\ KB \div 5\ seconds = 0.4\ KBps = 3.2 Kbps$$

However, that value is misleading because that need is only present for a total of five seconds. In addition, it would be tedious at best to tabulate the periodic communication needs of every device and determine an equivalent bandwidth need.

An alternative approach would be to simply break down every device’s communication on a per-second basis across a single day. In this case, the DMS would require the following equivalent bandwidth:

$$3.2\ Kb \div 1440\ seconds = 0.002\ Kbps$$

While this is numerically correct, such a process doesn't take the timing of the various needs into consideration. If several devices are transmitting simultaneously, the bandwidth needs could quickly accumulate. This process could cause a significant increase in the time it takes to transmit data, in turn causing several problems as data would not be received on time and events that need to take place in real time would be late.

As a result of the above issues, the design methodology utilized for data communications assumes that all data communications are constant. In other words, all devices are constantly transmitting information at their maximum rate. While this methodology errs on the side of designing for an increased bandwidth need, it removes much of the tedious work and inaccuracies of trying to pinpoint when and how often a device communicates.

DATA COMMUNICATIONS METHODOLOGY

An overview of the process presented in the guidebook for designing or evaluating data communication solutions is illustrated in the flowchart in Figure 1. Each of the seven parts of the methodology is referenced to a section in the guidebook where detailed information is provided. Additional information on each section of the procedure is provided in the following sections.

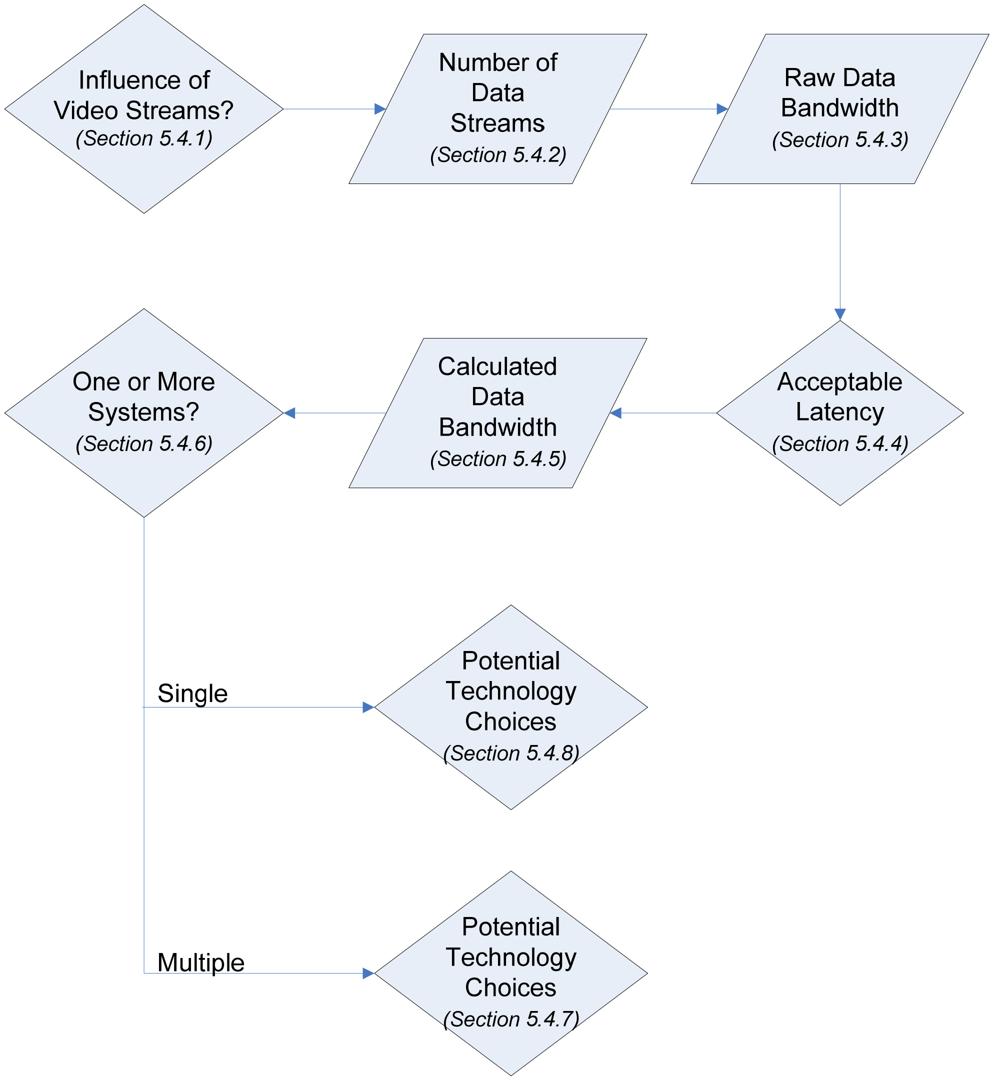


Figure 1. Flowchart for Data System Design/Evaluation.

Influence of Video Streams

The first section of the data methodology procedure determines the presence of video streams. While this may be somewhat puzzling at first glance, video takes a considerably greater amount bandwidth than data communications. If video will be present and will be sharing the same communication system, the appropriate methodology to use is the video design methodology.

Number of Devices

The second part of the procedure identifies both the type and numbers of the various devices that are present in the system today and that must be accommodated in the future. A breakdown by type of device is provided simply to help the designer identify different data sources. Other than the bandwidth in use, there is no inherent difference in the data stream from one type of device to another.

Determine Raw Data Bandwidth

The third part of the procedure identifies the bandwidth that each device uses. If average bandwidth numbers are not known, the procedure provides default numbers in accordance with accepted designed principles. As discussed previously, this procedure assumes that all devices are on and transmitting at all times.

Adjustment for Latency

As discussed earlier, latency is the delay between any two points in the system. Latency is a fairly important consideration in the design or evaluation of communication systems because it can have a significant effect on the final result. In the fourth part of the procedure, designers are asked to specify a latency or utilize a suggested default.

Determine Calculated Data Bandwidth

The fifth part of the data communications procedure assesses the bandwidth the design will use. This section essentially inflates the raw bandwidth necessary by a factor of safety based on latency requirements. The factor of safety helps to ensure that the design situation is not exceeded and that overall system delays have a negligible impact on the operations of the communications system.

The equation to use for calculating the required bandwidth is:

$$Raw\ Bandwidth \div \{1 - Latency\} = Calculated\ \ Bandwidth$$

Examine the Use of Single or Multiple Systems

The sixth part of the procedure is a critical juncture in the data communications design process. This step is where the final design situation is determined. It is entirely possible that many deployments need to utilize multiple individual communication solutions as opposed to a single comprehensive system. This portion of the procedure identifies which is the best design scenario and directs the designer to an appropriate solution set of communication technologies.

Potential Technology Choices

The final step in the design situation is determining the potential technology choices. As indicated in the sixth part of the procedure, the methodology can accommodate the design of either multiple smaller solutions or a single comprehensive communications system. Figure 2 shows a graphic where the applicable data communication technologies are arranged on a logarithmic scale according to the usable bandwidth.

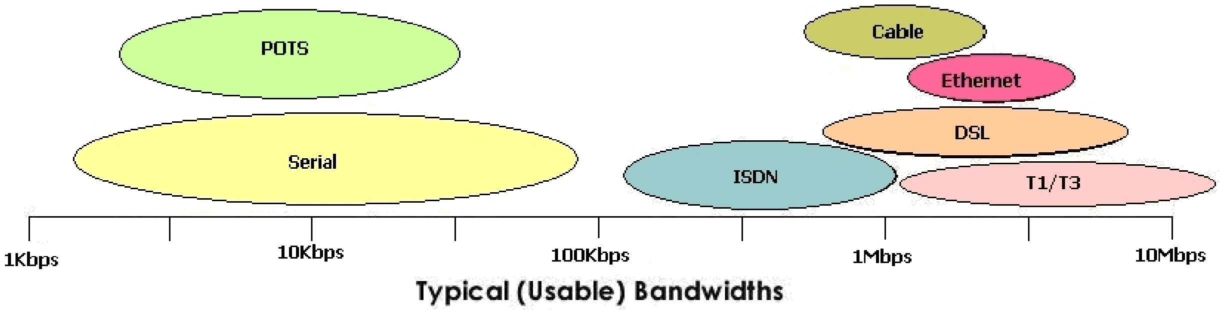


Figure 2. Technology Choices for Data Communications.

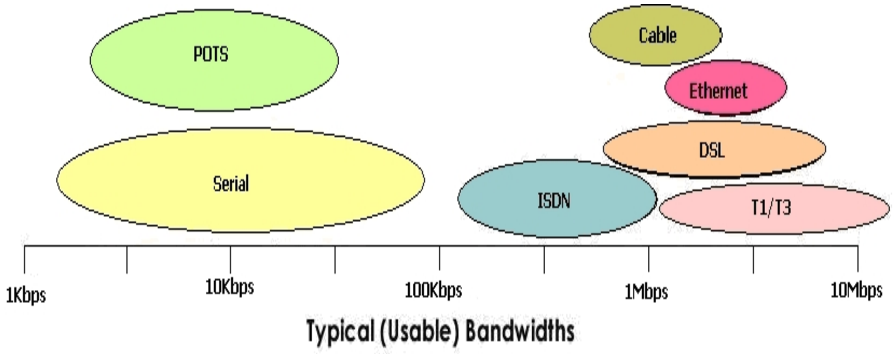
Drawing a vertical line across this graphic, corresponding to the required bandwidth, identifies the subset of technology choices. In the individual deployment situation, the technology choices underneath the line should be considered. In the single, comprehensive system solution, all technologies to the right of the drawn line should be considered.

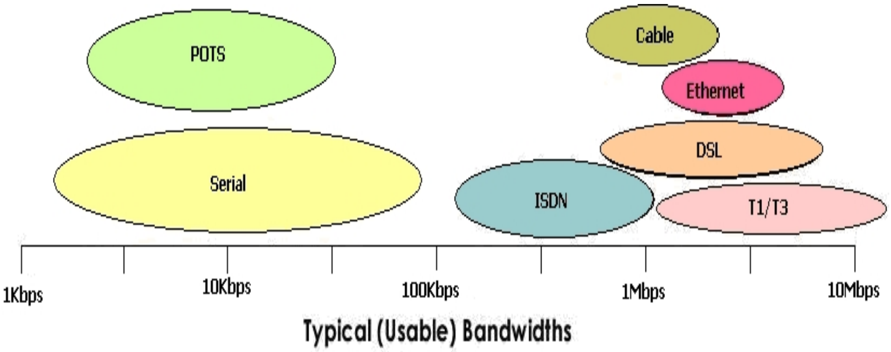
Data Methodology Implementation

Table 6 shows the complete methodology for data communications.

Table 6. Data Communications Design/Evaluation Worksheet.

<table>
<tr><th colspan="5">Data Communications Design Worksheet</th></tr>
<tr><td rowspan="2">Presence of Video Streams
(Section 5.4.1)</td><td>1.</td><td>Are video streams in use now or will they be in the future?
☐ YES ☐ NO
If 'NO,' proceed to Question 3.</td><td>1.</td><td>▨</td></tr>
<tr><td>2.</td><td>Are the video streams and data being transmitted together over the same communications system in the field?
☐ YES ☐ NO
If 'YES,' you do not need this worksheet, you need the Digital Video Communications Design Worksheet
If 'NO', proceed to Question 3.</td><td>2.</td><td>▨</td></tr>
<tr><td>Number of Devices
(Section 5.4.2)</td><td>3.</td><td>How many of the following devices do you have?
<table>
<tr><th></th><th></th><th colspan="2">Number of Devices</th></tr>
<tr><th></th><th>Device Type</th><th>Current</th><th>Future</th></tr>
<tr><td>**3a.**</td><td>Dynamic Message Signs</td><td></td><td></td></tr>
<tr><td>**3b.**</td><td>Vehicle/Roadway Detectors</td><td></td><td></td></tr>
<tr><td>**3c.**</td><td>TxDOT LCU</td><td></td><td></td></tr>
<tr><td>**3d.**</td><td>TxDOT SCU</td><td></td><td></td></tr>
<tr><td>**3e.**</td><td>RWIS</td><td></td><td></td></tr>
<tr><td>**3f.**</td><td>Weather Stations</td><td></td><td></td></tr>
<tr><td>**3g.**</td><td>Ramp Meters</td><td></td><td></td></tr>
<tr><td>**3h**</td><td>PTZ Camera</td><td></td><td></td></tr>
<tr><td>**3i**</td><td>Traffic Controllers</td><td></td><td></td></tr>
<tr><td>**3j.**</td><td>Other</td><td></td><td></td></tr>
<tr><td>**3k.**</td><td>***Subtotals***</td><td></td><td></td></tr>
<tr><td>**3l.**</td><td>***TOTAL NUMBER OF DATA STREAMS
(Add 3k CURRENT + 3k FUTURE)***</td><td colspan="2"></td></tr>
</table>
TOTAL NUMBER OF DEVICES</td><td>3m.</td><td></td></tr>
<tr><td>Raw Data Bandwidth
(Section 5.4.3)</td><td>4.</td><td>**FOR ALL DEVICES, ASSUME CONSTANT TRANSMISSION**
<table>
<tr><th></th><th></th><th>Rate</th><th>Number</th><th>Bandwidth</th></tr>
<tr><td>**4a.**</td><td>**Known Data Bandwidth Calculation**
For devices with known rates enter the rate and number.</td><td></td><td></td><td></td></tr>
<tr><td>**4b.**</td><td>**Unknown Data Bandwidth Calculation**
For devices with unknown rates use 9.6 Kbps.</td><td></td><td></td><td></td></tr>
<tr><td>**4c.**</td><td colspan="2">**Total Bandwidth**
Total number should match line 3m.</td><td></td><td></td></tr>
</table>
TOTAL RAW DATA BANDWIDTH (Kbps)</td><td>4d.</td><td></td></tr>
</table>

<table>
<tr><td>Acceptable Latency (Section 5.4.4)</td><td>5.</td><td>Do you know what your acceptable latency is?
☐ YES ☐ NO
If ‘YES’ enter the value on Line 5.
If ‘NO’, assume 250 milliseconds and enter on Line 5</td><td>5.</td><td></td></tr>
<tr><td>Calculated Data Bandwidth (Section 5.4.5)</td><td>6.</td><td><table><tr><td>6a.</td><td>Raw Data Bandwidth, Kbps (from Line 4d)</td><td></td></tr><tr><td>6b.</td><td>Acceptable Latency (from Line 5)</td><td></td></tr><tr><td>6c.</td><td>Calculated Data Bandwidth, Kbps
Calculate using: $Line\ 6a \div \{1 - Line\ 6b\}$</td><td></td></tr></table>
CALCULATED DATA BANDWIDTH (Kbps)</td><td>6d.</td><td></td></tr>
<tr><td>Single or Multiple Systems (Section 5.4.6)</td><td>7.</td><td>Will all of the data streams be aggregated together on one communications system in the field?
☐ YES ☐ NO
If the answer is “NO’, please go to Question 9.</td><td>7.</td><td></td></tr>
<tr><td>Single System – Define Potential Technology Choices (Section 5.4.8)</td><td>8.</td><td>The figure below shows the broad range of technology solutions that are available. The scale is logarithmic. Using the value from Line 6d, draw a vertical line through the graph, representing the bandwidth needed. All of the choices to the <u>RIGHT</u> of the vertical line are potential choices.

After completing this question, please proceed to “Data System Summary.”</td><td>8.</td><td></td></tr>
</table>

<table>
<tr>
<td>Multiple Systems – Define Potential Technology Choices (Section 5.4.7)</td>
<td>9.</td>
<td>Design information provided suggests that multiple communication links will be utilized. Identify potential communication solutions for <u>EACH</u> field link by drawing a vertical line through the figure below with a typical (per location) bandwidth need (refer to Question 3). The choices immediately surrounding that line that represent purchased services (Ex: POTS, ISDN, DSL, T1/T3, Cable) should be investigated for their applicability.


After completing this question, please proceed to “Data System Summary”</td>
<td>9.</td>
<td></td>
</tr>
</table>

VIDEO COMMUNICATIONS

Video communications take significantly more bandwidth than data communications. The main reason of course is that the amount of information required to produce a picture is far greater than the amount of information required to, as an example, put a message on a DMS sign. In addition, because the camera views a scene that is constantly changing, the flow of information is constant. By comparison, a DMS can be told what message to display and no additional information is necessary.

The guidebook materials first educate the workshop participants about video communications. Video is governed by a combination of frame rate, resolution, and color depth. These three factors determine the uncompressed bandwidth in use by a video signal.

As an example, a typical computer screen resolution is 1024 x 768, meaning there are 1024 pixels horizontally and 768 pixels vertically. One frame at that resolution has to convey information about 786,432 individual points of light. The larger the resolution, the more bandwidth required to transmit the information. Some common video resolutions are 176 x 144 (QCIF), 352 x 288 (CIF), and 720 x 576 (D1).

The total bandwidth of a video stream can be calculated as the product of the resolution, frame rate, and color depth. As the example calculation below shows, a single stream of uncompressed video to a computer screen would take nearly 71 MBps.

$$1 \textit{ frame at } 1024 \textit{ x } 768 \textit{ resolution} = 786{,}432 \textit{ pixels per frame}$$

$$786{,}432 \textit{ pixels x } 3 \textit{ bytes per pixel color depth} = 2{,}359{,}296 \textit{ bytes per frame}$$

$$2{,}359{,}296 \textit{ bytes per frame x } 30 \textit{ frames per second} = 70{,}778{,}880 \textit{ bytes per second}$$

$$70{,}778{,}880 \textit{ bytes per second} = 70.8 \textit{ MBps} = 566 \textit{ Mbps}$$

Although the example above pertained to computers, the bandwidth of a single video stream from a camera is also significant. Consider the case of a video stream operating at a D1 resolution.

$$1 \textit{ frame at } 720 \textit{ x } 576 \textit{ resolution} = 414{,}720 \textit{ pixels per frame}$$

$$414{,}720 \textit{ pixels x } 3 \textit{ bytes per pixel color depth} = 1{,}244{,}160 \textit{ bytes per frame}$$

$$1{,}244{,}160 \textit{ bytes per frame x } 30 \textit{ frames per second} = 37{,}324{,}800 \textit{ bytes per second}$$

$$37{,}324{,}800 \textit{ bytes per second} = 37.3 \textit{ MBps} = 298.4 \textit{ Mbps}$$

The guidebook materials identify a number of solutions that could meet this bandwidth requirement, but the associated cost for even a single camera would be very significant. A small system of 10 cameras could potentially cost several million a year to bring back the video streams. The guidebook materials discuss the use of techniques to reduce the amount of video bandwidth, including the use of encoding. This would allow the video stream to be transported using a much smaller amount of bandwidth and, typically, reduced operating cost for the communications technology.

VIDEO COMMUNICATIONS METHODOLOGY

An overview of the process presented in the guidebook for designing or evaluating video communication solutions is illustrated in the flowchart in Figure 3. Each of the eight parts of the methodology is referenced to a section in the guidebook where detailed information is provided. Additional information on each section of the procedure is provided in the following sections.

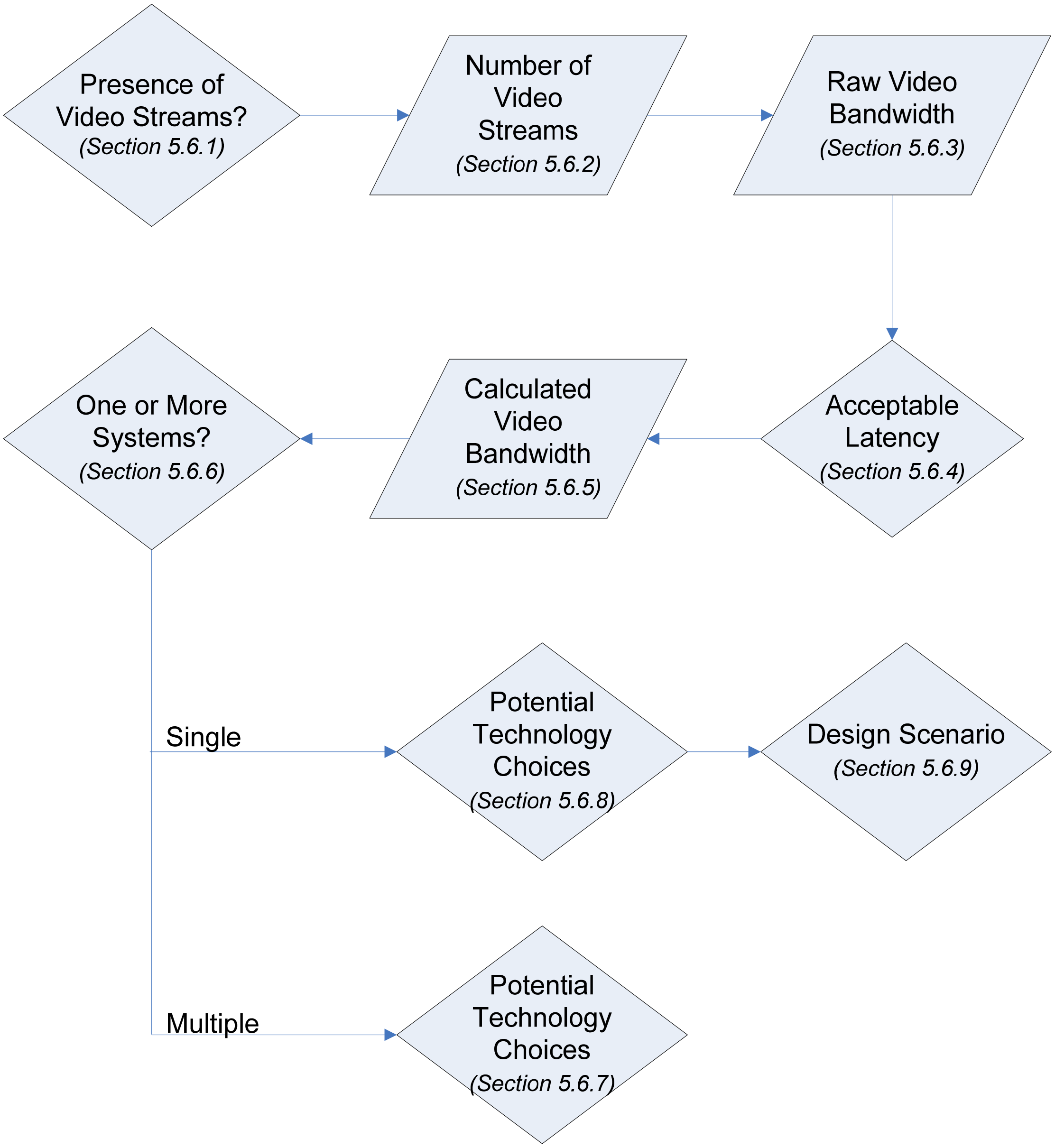


Figure 3. Flowchart for Video System Design/Evaluation.

Presence of Video Streams

The first section of the video methodology procedure determines if video is a part of the design situation. This step is simply provided as a check to ensure that the designer is utilizing the correct part of the design methodologies. Video takes a considerably greater amount of bandwidth and over-designing could result in greatly increased costs.

Number of Devices

The second part of the procedure identifies both the type and numbers of the various video streams that are present in the system today and that must be accommodated in the future. A breakdown by type of stream is provided simply to help the designer identify different video sources. Other than the bandwidth in use, there is no inherent difference in the video stream from one type of device to another.

Determine Raw Video Bandwidth

The third part of the procedure identifies the bandwidth that will be used by each device. The procedure asks the designer to assign video streams to either a “Low”, “Medium”, or “High” quality to determine the bandwidth they will use. If bandwidth numbers are not known, the procedure provides default numbers in accordance with accepted designed principles.

Adjustment for Latency

As discussed earlier, latency is the delay between any two points in the system. Latency is a fairly important consideration in the design or evaluation of communication systems, because it can have a significant effect on the final result. In the fourth part of the procedure, designers are asked to specify a latency or utilize a suggested default.

Determine Calculated Video Bandwidth

The fifth part the video communications procedure assesses the bandwidth that will be used for the design. This section essentially inflates the raw bandwidth necessary by a factor of safety based on latency requirements. This step helps to ensure that the design situation is not exceeded and that overall system delays have a negligible impact on the operations of the communications system.

The equation to use for calculating the required bandwidth is:

$$Raw\ Bandwidth \div \{1 - Latency\} = Calculated\ \ Bandwidth$$

Examine the Use of Single or Multiple Systems

The sixth part of the procedure is a critical juncture in the video communications design process. This step is where the final design situation is determined. It is entirely possible that many deployments need to utilize multiple individual communication solutions as opposed to a single comprehensive system. This portion of the procedure identifies which is the controlling design scenario and directs the designer to an appropriate solution set of communication technologies.

Potential Technology Choices

The seventh step in the design situation is determining the potential technology choices. As indicated in the sixth part of the procedure, the methodology can accommodate the design of either multiple smaller solutions or a single comprehensive communications system. Figure 4 shows a graphic where the applicable video communication technologies are arranged on a logarithmic scale according to the usable bandwidth.

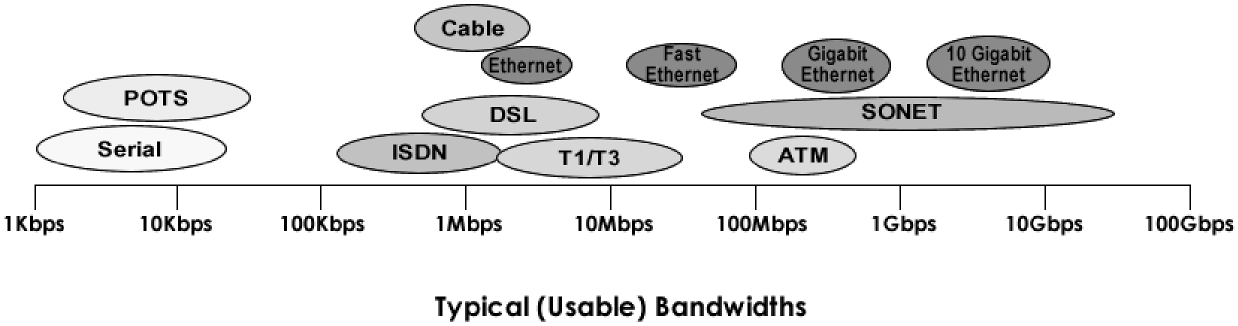


Figure 4. Technology Choices for Video Communications.

Drawing a vertical line across this graphic, corresponding to the required bandwidth, identifies the subset of technology choices. In the individual deployment situation, the technology choices directly underneath the line should be considered. In the single, comprehensive system solution, all technologies to the right of the drawn line should be considered.

Best Video Design Scenario

The final step in the video design methodology is to determine the most appropriate or best design situation. For video, this means either multicast or unicast operations. This part of the process asks a series of four questions which are used to guide the designer to the best solution for their particular deployment situation. Questions are asked in the following areas:

- Who will own the communications system?
- Does video need to be received at more than one location?

- What is the willingness to change equipment settings to accommodate video solutions?
- What is the primary constraint of the deployment (cost, bandwidth, or simplicity)?

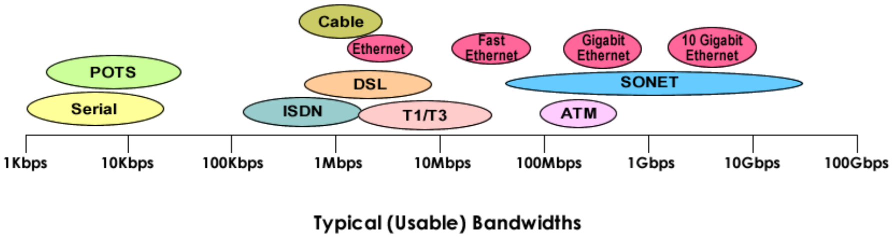
While other questions can certainly be identified, these four questions provide a design determination in 75 percent of the real-world situations that will be encountered. Achieving a higher percentage would require significantly more questions and greatly increase both the length and complexity of the design procedure.

Video Methodology Implementation

Table 7 shows the complete methodology for data communications.

Table 7. Video Communications Design/Evaluation Worksheet.

<table>
<tr><th colspan="5">Digital Video Communications Design Worksheet</th></tr>
<tr><td>Presence of Video Streams (Section 5.6.1)</td><td>1.</td><td>Are video streams in use now or will they be in the future?
☐ YES ☐ NO
If ‘YES’ proceed with Question 2.
If ‘NO’, you do not need this worksheet</td><td>1.</td><td>▨</td></tr>
<tr><td>Number of Video Streams (Section 5.6.2)</td><td>2.</td><td>How many video streams?
<table>
<tr><th></th><th></th><th colspan="2">Number of Streams</th></tr>
<tr><th></th><th>Type of Video Streams</th><th>Current</th><th>Future</th></tr>
<tr><td>2a.</td><td>PTZ Color Video Streams</td><td></td><td></td></tr>
<tr><td>2b.</td><td>PTZ B/W Video Streams</td><td></td><td></td></tr>
<tr><td>2c.</td><td>Static Color Video Streams</td><td></td><td></td></tr>
<tr><td>2d.</td><td>Static B/W Video Streams</td><td></td><td></td></tr>
<tr><td>2e.</td><td>Intersection Detection Cameras</td><td></td><td></td></tr>
<tr><td>2f.</td><td>Subtotals</td><td></td><td></td></tr>
<tr><td>2g.</td><td>TOTAL NUMBER OF VIDEO STREAMS (Add 2f CURRENT + 2f FUTURE)</td><td colspan="2"></td></tr>
</table>
TOTAL NUMBER OF VIDEO STREAMS</td><td>2h.</td><td></td></tr>
<tr><td>Raw Video Bandwidth (Section 5.6.3)</td><td>3.</td><td>
<table>
<tr><th></th><th>Type of Video Stream</th><th>Rate</th><th>Number</th><th>Bandwidth</th></tr>
<tr><td>3a.</td><td>Low Speed Video Stream
If rate unknown, use 0.5 Mbps.</td><td></td><td></td><td></td></tr>
<tr><td>3b.</td><td>Medium Speed Video Stream
If rate unknown, use 2.0 Mbps.</td><td></td><td></td><td></td></tr>
<tr><td>3c.</td><td>High-Speed Video Stream
If rate unknown, use 6 Mbps.</td><td></td><td></td><td></td></tr>
<tr><td>3d</td><td colspan="2">TOTALS (Add sum of 3a through 3c) CHECK: Total Number of Streams should match Line 2h</td><td></td><td></td></tr>
</table>
TOTAL RAW VIDEO STREAM BANDWIDTH (Mbps)</td><td>3e.</td><td></td></tr>
<tr><td>Acceptable Latency (Section 5.6.4)</td><td>4.</td><td>Do you know what your acceptable latency is?
☐ YES ☐ NO
If ‘YES’ enter the value on Line 4.
If ‘NO’, assume 250 milliseconds and enter on Line 4</td><td>4.</td><td></td></tr>
<tr><td>Calculated Video Bandwidth (Section 5.6.5)</td><td>5.</td><td>
<table>
<tr><td>5a.</td><td>Raw Video Bandwidth, Mbps (from Line 3e)</td><td></td></tr>
<tr><td>5b.</td><td>Acceptable Latency (from Line 4)</td><td></td></tr>
<tr><td>5c.</td><td>Calculated Video Bandwidth, Mbps
Calculate using: $Line\ 5a \div \{1 - Line\ 5b\}$</td><td></td></tr>
</table>
CALCULATED VIDEO STREAM BANDWIDTH (Mbps)</td><td>5d.</td><td></td></tr>
</table>

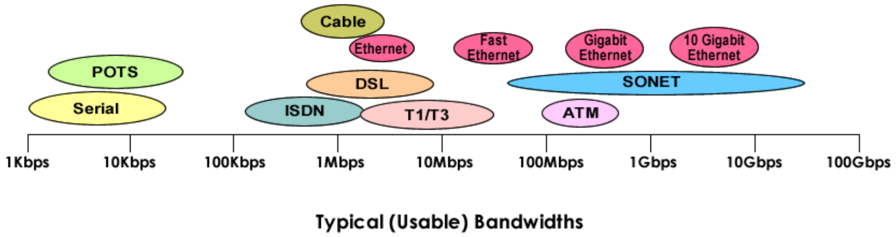
Single or Multiple Systems *(Section 5.6.6)*	6.	Will all of the video streams be aggregated together on one communications system in the field? ☐ YES ☐ NO If the answer is 'NO', please go to Question 13.	6.	
Single System – Define Potential Technology Choices *(Section 5.6.8)*	7.	The figure below shows the broad range of technology solutions that are available. The scale is logarithmic. Using the value from Line 5d, draw a vertical line through the graph, representing the bandwidth you need. All of the choices to the *RIGHT* of the vertical line are potential choices.  	7.	
Single System – Most Appropriate Design Scenario *(Section 5.6.9)*	8.	Will you be able to own, operate, and maintain 100 percent of your communications network internal to your agency? ☐ YES ☐ NO If the answer is YES,' please proceed to Question 9. If the answer is 'NO,' you should design for unicast operations. *After completing this question, please proceed to "Video System Summary."*	8.	
	9.	Does the same video stream need to be received at more than one location? ☐ YES ☐ NO	9.	
	10.	Are you willing to manually reconfigure video streams? ☐ YES ☐ NO	10.	
	11.	What is the PRIMARY design constraint? (Please select one) ☐ Simplicity (S) ☐ Cost (C) ☐ Bandwidth (B)	11.	

<table>
<tr>
<td>Single System – Most Appropriate Design Scenario (Section 5.6.9)</td>
<td>12.</td>
<td>What design situation is most applicable to your situation?

Enter the results from Question 9 through 11 in the table below to find the most appropriate design for your situation.

<table>
<tr><td>Q9</td><td>Y</td><td>Y</td><td>Y</td><td>Y</td><td>Y</td><td>Y</td><td>N</td><td>N</td><td>N</td><td>N</td><td>N</td><td>N</td></tr>
<tr><td>Q10</td><td>Y</td><td>Y</td><td>Y</td><td>N</td><td>N</td><td>N</td><td>Y</td><td>Y</td><td>Y</td><td>N</td><td>N</td><td>N</td></tr>
<tr><td>Q11</td><td>S</td><td>B</td><td>C</td><td>S</td><td>B</td><td>C</td><td>S</td><td>B</td><td>C</td><td>S</td><td>B</td><td>C</td></tr>
<tr><td>Design for</td><td>(a)</td><td>Multicast</td><td>Multicast</td><td>Unicast</td><td>(a)</td><td>(b)</td><td>Unicast</td><td>Multicast</td><td>Multicast</td><td>Unicast</td><td>Unicast</td><td>Unicast</td></tr>
</table>
(a) Design goals are somewhat at odds. Multicast is favored.
(b) Design goals are somewhat at odds. Unicast is favored.

After completing this question, please proceed to "Video System Summary."</td>
<td>12.</td>
<td></td>
</tr>
<tr>
<td>Multiple Systems – Define Potential Technology Choices (Section 5.6.7)</td>
<td>13.</td>
<td>Design information provided suggests that multiple communication links will be utilized. Identify potential communication solutions for <u>EACH</u> field link by drawing a vertical line through the figure below with a typical (per location) bandwidth need (refer to Question 3). The choices immediately surrounding that line that represent purchased services (Ex: POTS, ISDN, DSL, T1/T3, Cable) should be investigated for their applicability.



After completing this question, please proceed to "Video System Summary."</td>
<td>13.</td>
<td></td>
</tr>
</table>

Additional Design Considerations

As discussed previously, the design of a communication solution is often more of an art than an exact science. Multiple solutions can be created for nearly every need. While the methodology presented here and in the guidebook covers numerous technologies and implementations, they cannot cover every design situation.

Table 8 lists several areas of any communication system that warrant additional consideration. These areas include items such as funding. One of the critical issues that faces ITS deployments is a lack of funding for ongoing operations and maintenance. It is entirely conceivable that a communications system choice might be made on the basis of long-term funding availability.

Another critical area identified in the table across several categories is training. The implementation of advanced communication systems may require some significant additional expertise at all levels of the organization. Staff may need training in proper maintenance of equipment. Operators and managers may need to have training to understand the capabilities of new deployments and how these fit into the normal activities.

The prudent designer should take items such as those identified in Table 8 into consideration before making a final design decision.

Table 8. Additional Considerations for All Deployments.

Deployment Locations	• Field cabinets? • Transportation Management Centers? • Controlled access areas? • Hardened equipment will cost more. • Additional security may be necessary to protect equipment.
Project Funding	• What is included in the system cost? • What other equipment is necessary? • Is training required? • Are funds available for maintenance? • Is there a budget for monthly operating cost if using purchased services?
	• Is this a budgeted item? • Is this a one-time purchase? • Are there provisions that have to be met?
Construction Timeline	• Purchased services can be installed more quickly. • Can some installation be done in-house? • Does construction have to take place within the bid process?
Ease of Implementation	• Can some work be done in-house? • Can some equipment be pre-configured? • Can equipment be standardized with other deployments?
System Expansion Capability	• Can the system be expanded in the future? • Will equipment have to be added or replaced? • How compatible will future equipment be (changing standards)?
Staff Expertise	• How much expertise is needed? • Can staff on hand do the job? • Are new hires necessary? • How will staff training be paid for?
System Managers	• Are system managers knowledgeable enough to integrate new deployments and resources? • How much training is necessary? • Are new hires necessary?
System Maintainers	• Is specialized communications training necessary? • Who will pay for training costs? • If training is available, who is eligible to receive it? • Are new hires necessary?

CASE STUDIES

The guidebook utilizes case studies to help teach the methodology for data and video design and evaluation. As originally envisioned, the case studies would have been actual deployment situations in TxDOT district offices. However, the timing of these deployment situations and the course of the research project were not conducive to utilizing real-world case studies. Researchers created case studies and included these in the guidebook to help teach and communicate the concepts of the design methodologies.

The description, objectives, and solution of each case study are detailed below. The reader is referred to Chapter 7 in the communications guidebook for the detailed analysis of these design problems.

Data Case Study

Baker, Texas, a mid-size city located in a hilly region, has recently seen a surge in its population. Severe weather conditions often occur on a major roadway near town. The city wishes to alert drivers to these severe conditions as rapidly as possible to promote safer driving and help reduce accidents.

The design calls for installing loop detectors on both sides of the roadway to measure volumes and speeds. In addition, the city will install a weather station and two DMS signs to warn drivers of impending weather conditions. There is also a new isolated signal installation along the affected stretch of roadway that Baker would like to communicate with as well. It is possible that during adverse conditions, Baker may alter the timing of the light. The combination of all of these countermeasures will increase the roadway safety in the areas and reduce the legal exposure to the city.

Because these types of deployments are relatively new to the city, there is no established infrastructure that is available for communications.

Objectives

The city of Baker would like to install communications infrastructure to support the:

- installation of loop detectors along both sides of the roadway to monitor the speed and volume of traffic,

- installation of two DMS signs to relay information to drivers along dangerous sections of road,
- installation of a weather station near the roadway to detect weather conditions, and
- communication with the traffic signal at the isolated intersection.

Solution

Table 9 shows a summary of the information from this case study. The city of Baker should consider building a single aggregated communications solution for their needs. The instructor notes for this case study detail that a significant consideration could be information security. The cable and DSL solutions are Internet based technologies, which utilize a different setup. Baker would have to ensure that field equipment is protected against security problems, such as viruses and hacking attempts. On the other hand, historically, ISDN has not been as reliable as some of the other technologies and may prove to be more problematic.

Table 9. Data Case Study Results.

Data System Summary (Please record the results of your worksheet analysis.)	
Data Bandwidth (from Line 6d)	102.4 Kbps
System Type (circle one)	Multiple links [✓ **Single aggregated network**]
Technologies under consideration (list top three choices)	1. ISDN 2. CABLE 3. DSL

Video Case Study

Smallville, Texas, has just finished construction of a new state-of-the-art civic center. The center is located on an intersection on one of two main highways that run through town. During special events, traffic around the new center often becomes congested and police are called to direct traffic.

Smallville would like to install a video monitoring system at the intersection so that the intersection and surrounding traffic can be remotely monitored during these events. The city would like four stationary cameras that each show one direction at the intersection. They would also like 1 PTZ camera located somewhere at or near the intersection that they can control to see the surrounding area. The video feeds would be viewed from a control center located at the city police station, which is located a few miles away.

The four intersection cameras can be displayed together in a quad view, while the PTZ camera would need a separate stream. The main purpose of the intersection cameras would be to show the status of the intersection, and not show details of each car passing through. This use would enable the quad feed to be low quality-streams. The PTZ camera would need to be a medium- quality feed so that the operator of the monitoring station could focus on details if needed.

The city would also like to obtain traffic counts at the intersection to study the impact of these events on the local traffic and economy. The counts would need to contain the number of cars passing through each direction of the intersection, including both straight and turning vehicles. These data must be able to be viewed live during an event, but must also be stored to a database for further analysis.

Objectives

The city of Smallville, Texas, would like to deploy equipment to:

- receive video feeds at a central location from an intersection for viewing/monitoring proposes,
- obtain vehicle count records for all directions of the intersection and store data to a database for future analysis, and
- enable PTZ for one camera to monitor the intersection and surrounding areas.

Solution

Table 10 shows a summary of the information from this case study. Of the identified solutions, DSL is the most promising solution for Smallville as they do not anticipate being able to own and operate their own communications infrastructure. The bandwidth needs exceed that of a single T1 and the use of a T3 for this level of bandwidth may be fiscally questionable, depending on pricing.

While this case study resulted in a single answer, the choice is not without some complications. Because DSL is geared for an Internet type of deployment, typically the download speed is very fast and the upload speed is considerably slower. In this situation, the upload speed will need to be significant to accommodate the 5.3 Mbps required bandwidth. This option will entail detailed discussions with the local DSL service provider to ensure adequate service. A T3 line would, however, have sufficient capacity and may be a viable alternative depending on the cost.

Table 10. Video Case Study Results.

Video System Summary (Please record the results of your worksheet analysis.)	
Video Bandwidth (from Line 5d)	5.3 Mbps
System Type (circle one)	Multiple links [✓ **Single aggregated network**]
Technologies under consideration (list top three choices)	1. DSL 2. T1/T3 3. Ethernet
Design Situation (circle one)	[✓ Unicast] Multicast

WORKSHOP MATERIALS

INTRODUCTION

The complete set of workshop materials includes the following:

- participant's notebook,
- PowerPoint slides, and
- instructor's notebook.

These items all work in combination to provide TxDOT with a complete set of material that they can use to teach the course in the future.

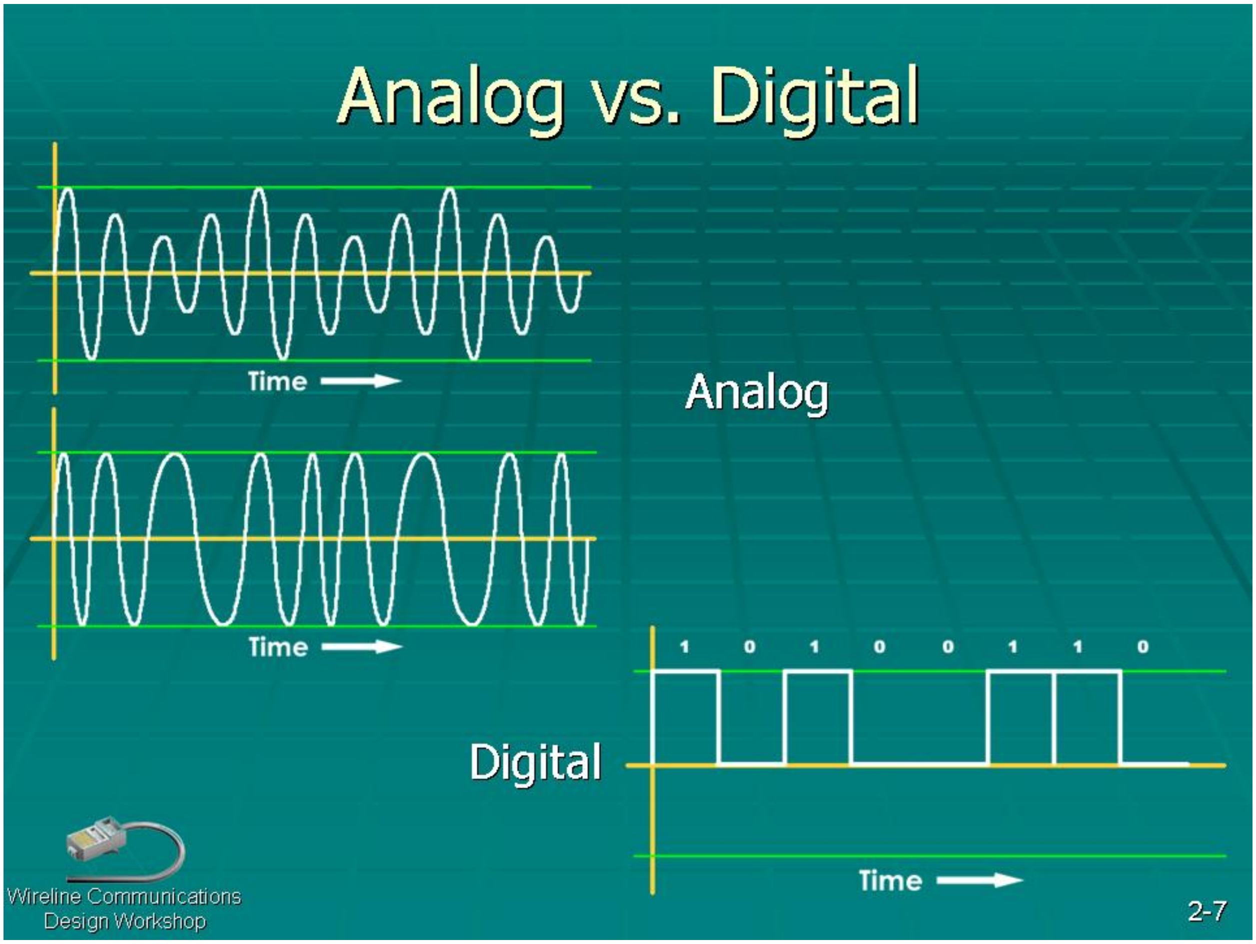
PARTICIPANT'S NOTEBOOK

The participant's notebook is the guidebook. As detailed in earlier sections of this report, the guidebook contains a significant amount of fundamental knowledge pertaining to communications. The guidebook also contains the design methodologies and detailed explanations of each section. The guidebook concludes with case studies demonstrating the use of the design methodologies and a glossary of terms used throughout the material.

It is anticipated that the guidebook will be a handy shelf reference for many aspects of designing communication systems and understanding communication fundamentals. For that reason, the guidebook was written with complete information in every major section, even if repeated from previous or similar sections.

POWERPOINT SLIDES

The PowerPoint slides are the hearth of the teaching materials prepared for TxDOT. Each slide was designed to convey a discrete unit of information and build upon the previous slide. In many cases, slides have been created that are interactive to help elicit class interaction with the instructor. Figure 5 shows a typical PowerPoint slide. Each slide is branded with the name of the workshop and a page number to help the instructor keep track of the progress of the class materials.



Analog vs. Digital

Analog

Digital

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2-7

Figure 5. Typical PowerPoint Slide Used for Workshop Instruction.

The complete set of PowerPoint slides was delivered to TxDOT on a CD-ROM. The listing below shows how the chapters of the guidebook were grouped into modules for teaching purposes.

- Module 1 – Chapter 1
- Module 2 – Chapter 2
- Module 3 – Chapter 3
- Module 4 – Chapter 4
- Module 5 – Chapters 5 and 6
- Module 6 – Chapters 7 and 8

Table 11 identifies the learning objectives that were identified for each module of the workshop materials.

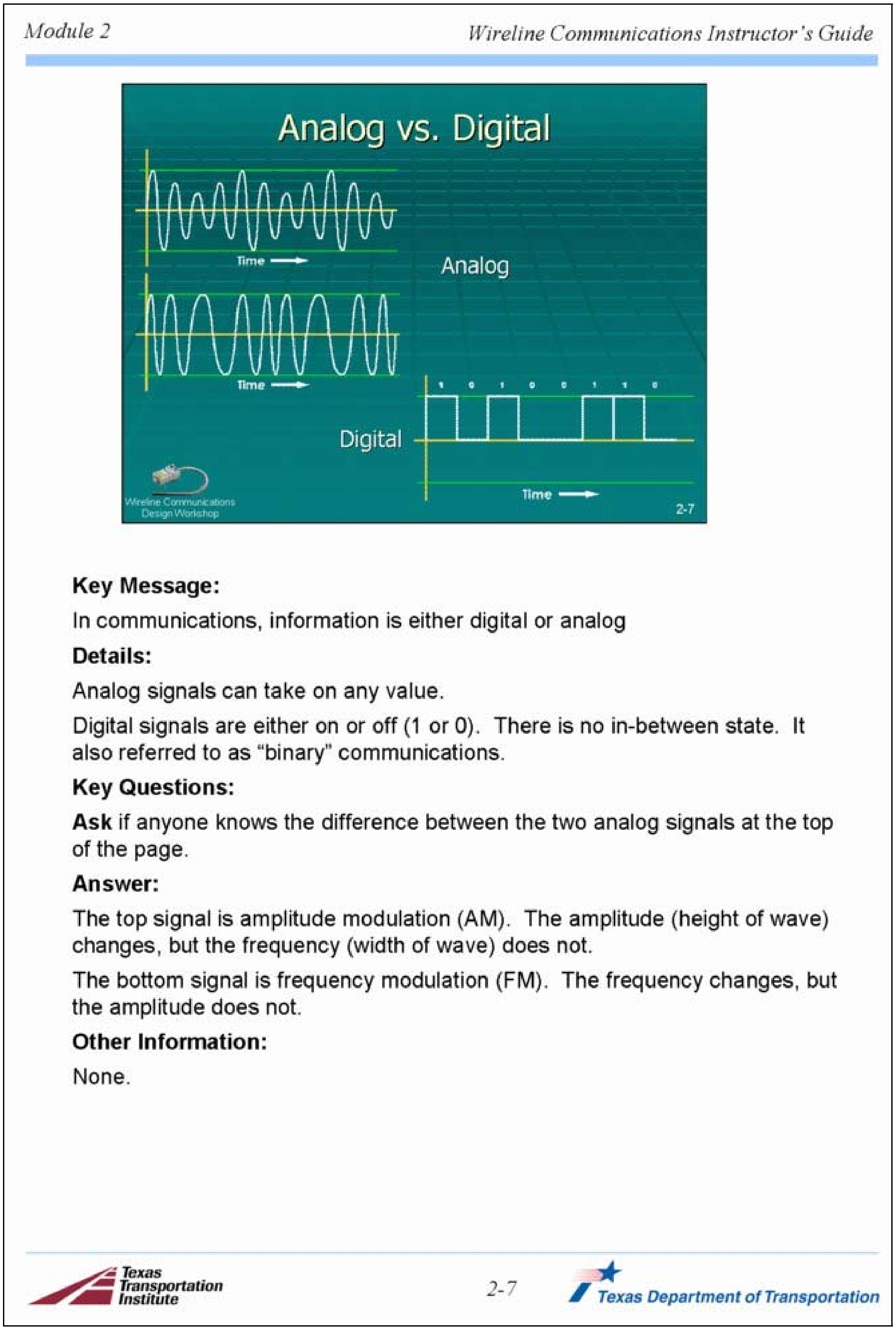
Table 11. Module Learning Objectives.

Module		Learning Objectives
1.	Introduction	N/A
2.	Basics of Wireline Communication	1. Understand the basic concepts of communications. 2. Recognize and be able to discuss the various media types and typical connectors. 3. Understand the typical "units" associated with sending and receiving communications.
3.	Understanding Telecommunication Protocols and Topologies	1. Describe the basic traits of a protocol and the performance of some of the more commonly used protocols. 2. Recognize and understand the differences between the types of network topologies. 3. Understand special communication topics including spanning tree protocol, tunneling, video encoding, security, and hardened equipment.
4.	Technology Choices	1. Summarize the different types of communication technologies. 2. Differentiate the costs and uses of each technology. 3. Identify supported protocols for each technology.
5.	System Design and Evaluation	1. Understand the components of the evaluation methodology for assessing communications alternatives. 2. Use the methodology to arrive at a solution set. 3. Evaluate the pros, cons, and constraints of the solution set.
6.	Flow Charts, Case Studies, and Class Exercise	1. Apply the methodology to case studies. 2. Apply the methodology to real-world applications.

INSTRUCTOR’S NOTEBOOK

The instructor’s notebook for this workshop was designed to be an easy reference guide for the workshop instructor. The front matter of the instructor’s notebook details the objectives of the learning modules and the typical workshop agenda. The primary use of the instructor’s notebook, however, is to convey pertinent information related to each slide used during the course.

This information is relayed through the use of instructor’s notes. Each note has a standard format that includes the Key Message, Detailed Information, Key Questions, and Other Information. Figure 6 shows a typical page from the instructor’s notebook.



Module 2 *Wireline Communications Instructor's Guide*

Key Message:

In communications, information is either digital or analog

Details:

Analog signals can take on any value.

Digital signals are either on or off (1 or 0). There is no in-between state. It also referred to as "binary" communications.

Key Questions:

Ask if anyone knows the difference between the two analog signals at the top of the page.

Answer:

The top signal is amplitude modulation (AM). The amplitude (height of wave) changes, but the frequency (width of wave) does not.

The bottom signal is frequency modulation (FM). The frequency changes, but the amplitude does not.

Other Information:

None.

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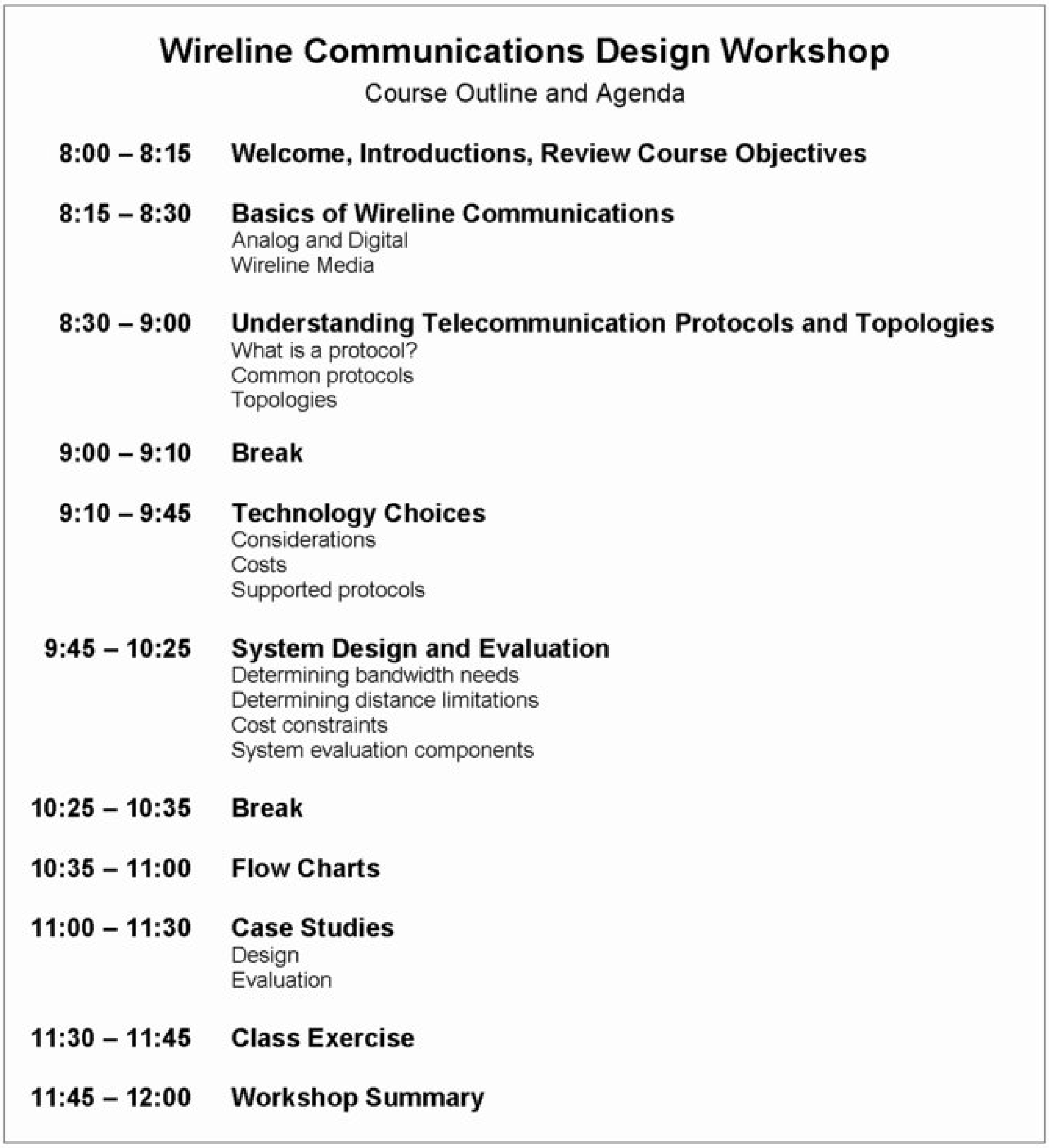
Figure 6. Typical Instructor's Note Page.

ADDITIONAL WORKSHOP INFORMATION

The workshop was designed to be taught in four hours. With the amount of information contained in the guidebook, this goal is an ambitious undertaking. Not every topic can be discussed in detail. It is important to remember that the guidebook was also written to be a shelf reference. Figure 7 shows the course outline and agenda along with suggested timeframes. The instructor should note the break times as these will decrease the amount of time available to teach course material.



Wireline Communications Design Workshop

Course Outline and Agenda

8:00 – 8:15	**Welcome, Introductions, Review Course Objectives**
8:15 – 8:30	**Basics of Wireline Communications** Analog and Digital Wireline Media
8:30 – 9:00	**Understanding Telecommunication Protocols and Topologies** What is a protocol? Common protocols Topologies
9:00 – 9:10	**Break**
9:10 – 9:45	**Technology Choices** Considerations Costs Supported protocols
9:45 – 10:25	**System Design and Evaluation** Determining bandwidth needs Determining distance limitations Cost constraints System evaluation components
10:25 – 10:35	**Break**
10:35 – 11:00	**Flow Charts**
11:00 – 11:30	**Case Studies** Design Evaluation
11:30 – 11:45	**Class Exercise**
11:45 – 12:00	**Workshop Summary**

Figure 7. Wireline Communications Design Workshop—Course Outline and Agenda.

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