Technical Report Documentation Page

1. Report No. FHWA/TX-05/0-4449-1	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle COST-EFFECTIVE STRATEGIES FOR COMMUNICATION WITH REMOTE SURVEILLANCE STATIONS		5. Report Date October 2003 Revised April 2005 6. Performing Organization Code
7. Author(s) Yi-Chang Chiu, Carl Haas		8. Performing Organization Report No. 0-4449-1
9. Performing Organization Name and Address Center for Transportation Research The University of Texas at Austin 3208 Red River, Suite 200 Austin, TX 78705-2650		10. Work Unit No. (TRAIS) 11. Contract or Grant No. 0-4449
12. Sponsoring Agency Name and Address Texas Department of Transportation Research and Technology Implementation Office P.O. Box 5080 Austin, TX 78763-5080		13. Type of Report and Period Covered Research Report September 2002 – October 2003 14. Sponsoring Agency Code
15. Supplementary Notes Project conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration, and the Texas Department of Transportation.		

16. Abstract

The advances of modern communication technologies have changed the way the roadway information is collected. Innovative surveillance systems powered by various communication technologies have installed to support various transportation operations. The abundance of available communication technologies and multiple available communication system configurations presents overwhelming challenges for traffic engineers in selecting proper communication technologies for user of various traffic operation and ITS applications.

The objective of this research is to propose an effective approach to characterize available communication technology choices, and analyze how they can be applied to various traffic operations. Of particular interest is to develop a guidebook to facilitate the decision-making in choosing appropriate communication technology given the operational requirements and decision objectives. Because of the fast-paced developments in communication technologies, a web-based Knowledge Management System that enables on-line learning of applications vs. communication technology choices, as well as continual updates of the technology choice set has been developed to ensure the continual usability of this research product.

17. Key Words Remote surveillance stations, communication technologies, ITS, traffic operations, Knowledge Management Systems.		18. Distribution Statement No restrictions. This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161; www.ntis.gov.	
19. Security Classif. (of report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of pages 156	22. Price

Form DOT F 1700.7 (8-72)   Reproduction of completed page authorized

COST-EFFECTIVE STRATEGIES FOR COMMUNICATION WITH REMOTE SURVEILLANCE STATIONS

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CTR Research Report:	0-4449-1
Report Date:	October 2003; Revised April 2005
Research Project:	0-4449-1
Research Project Title:	Cost-Effective Strategies for Communication with Remote Surveillance Stations

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Acknowledgments

Many people made invaluable contributions to this research project. The authors wish to acknowledge the guidance of the TxDOT project panel: Program Coordinator Carlos Chavez, Director of Transportation Operations (ELP); Project Director Richard Reeves (TRF, now retired); Project Advisors Billy Manning (FTW), Richardo Cortez (ELP), Charles Brindell (TRF), Steven Barnett (TRF), and Al Kosik (TRF) who provided continuous guidance during the course of the project. We also wish to acknowledge the contributions of Brian Burk (AUS), Nelson Wellspeak (FTW), David Fink (HOU), John Gaynor (HOU), Richard Cortez (ELP) and Brian Fariello (SAN) who provided valuable comments at our on-site interviews. In addition, Dr. Steve Riter, Provost of UTEP, who provided critical research infrastructure for this project is also acknowledged.

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Chapter 1. Introduction

While major installations to support advanced traffic management applications are being deployed along Texas's major urban freeways, the need for surveillance and/or detector capabilities also exists in numerous remote locations with no established telecommunications capability for the transmission of roadway-related data. The abundance of available communication technology choices, ranging from the decades-old but robust technologies (e.g., analogue radio, spread spectrum radio, microwave, etc.) to the state-of-the-art and soon-be-available technologies (e.g., 3G cellular wireless), presents difficult challenges for traffic engineers in deciding upon a cost-effective means of data transmission from a remote location to a freeway traffic management center.

In reality, not all technology options are suitable for the desired application. In conjunction with the application, the availability of site characteristics such as power, line of sight, transmission distance to adjacent relay/receiving site, transmission data rate requirements, frequency, and bandwidth will determine the range of options available and generally point to a specific technology choice. Furthermore, for a particular application, multiple communication system configurations that satisfy the application's functional and physical requirements are likely to exist. Different configurations involve distinct wireless or wireline technologies. Under such a circumstance, choosing the most suitable configuration/technology becomes a challenging task for TxDOT engineers.

What is required to assist TxDOT engineers in their planning is an application guide for intelligent transportation systems (ITS) communications. Covering wireline and wireless technologies, the guide should start with the traffic application as the basis for selection of a communication technology. The guide should include an examination of both the benefits and limitations of the various technologies and should address issues such as current and future availability, reliability of service, and cost expectations. Recognizing this need, the Federal Highway Administration (FHWA) has in the past prepared a special chapter on communication technologies in *Traffic Control Systems Handbook* (Federal Highway Administration, 1996). However, the technology is evolving at a fast pace, especially in the wireless arena, and documents soon become obsolete by the time they are published. In addition to the need to update the information in *Traffic Control Systems Handbook*, it is desirable to develop a mechanism for continual update of this information in order to keep it current for the use of traffic engineers. Furthermore, it is not sufficient simply to provide descriptive information on the various available technologies. What is needed is a specific set of procedures or decision aid that can be followed to identify the most appropriate configuration/technology for a particular application.

1.1. Research Objectives

The objectives of this research include:

1. Document the state-of-the-practice and past experience in designing wireless communication system configuration, identify deficiency of current practice, and survey commonly encountered issues by TxDOT engineers.

2. Survey prevalent and emerging wireless technologies and investigate how the future roadmap impacts traffic operation and ITS applications.

3. Develop an effective approach to characterize available communication technology choices and analyze how they can be applied to various traffic operation applications. It

is a priority to develop a guidebook to facilitate the decision-making in choosing appropriate communication technology given the operational requirements and decision objectives.

4. Design and implement a Web-Based Knowledge Management System (WBKMS) to facilitate the formation of institutional knowledge and to enable on-line learning of applications vs. communication technology choices, as well as continual updates of wire technology.

1.2. Outline of the Report

This report is structured as follows. Chapter 2 briefly reviews the transportation system operation and management applications that require communication technologies. This chapter highlights the ubiquitousness of communication technologies in modern traffic operation and management applications. Chapter 3 presents a brief survey of emerging communication technologies, with a particular emphasis on wireless technologies. Central to the discussion is the review of several prevalent and emerging wireless technologies. Chapter 4 describes the strategies and procedures for selecting cost-effective and minimal-risk communication configurations and wireless technologies. Chapter 5 presents the development of a Web-Based Knowledge Management System (WBKMS) that was designed to support and facilitate informed decision-making. Chapter 6 concludes this report. Several valuable documents are included in the appendix section. Appendix A summarizes six interviews with TxDOT engineers. Appendix B lists the data transmission rate requirements for common traffic operations and ITS applications. Appendix C includes the life-cycle cost and risk analysis worksheets for the ITS application example. Appendix D presents key sections and contents of the knowledge base that has been built in the WBKMS, developed as the product of this research project. Appendix E is a partial list of the wireless equipment and data service vendors/contractors who registered on the WBKMS.

Chapter 2. Transportation System Operations and Communication Applications

This chapter briefly discusses the transportation operation and management applications that require the use of communication technologies. They are articulated in the following sections.

2.1. Intelligent Transportation System (ITS) Applications

ITS developers, driven by the advances in communication technologies, continue pushing for the innovative use of traffic information. Several telecommunication and ITS developers are experimenting with using the huge existing user-base of wireless communication devices (i.e., cellular phone) for traffic monitoring. The concept could provide a low-cost alternative to the existing paradigms that require installing a large number of roadway devices.

Monitoring traffic via cellular phones does not require the specific tracking of an individual phone, reducing concerns regarding privacy. As for the safety of using a cell phone in a moving vehicle and the potential for some jurisdictions to ban this activity, the tracking technology will work just as well with the phone turned on, but not in use (i.e., in standby mode). In fact, a variation of the required technology has been in place since the inception of cellular phone service, allowing calls to be handed off from one cell site to another as the subscriber travels down the road.

Advanced traffic management systems (ATMS) and advanced traveler information systems (ATIS) that currently rely on fixed monitoring points, generally located at wide intervals, could be augmented by the addition of the data provided by the wireless system. This would allow highway managers to pinpoint trouble spots more accurately in areas where video camera coverage is not available. ATMS/ATIS systems currently in the planning or design stages could employ this technology to eliminate, or at least minimize, the need for fixed detection equipment, greatly reducing the system's installation and operating costs.

Prevalent technologies for such application primarily will be the cellular technologies, which have been evolving rapidly in recent years. Future discussions about the cellular technology and its operational issues are provided in sections 3.2.5, 4.1 and 4.2.

2.2. Highway Surveillance and Traffic Monitoring

Highway surveillance and traffic monitoring applications usually employ certain types of communication techniques to send data, voice, or video from the surveillance stations to either data processing outposts or traffic management centers (TMCs). Figure 2–1 illustrates the communications that take place under a typical TMC architecture. The general design considerations for choosing communication technologies are types of data to be transmitted (data, voice, or video), distance from surveillance stations to processing servers, physical limitations, availability of communication choices and associated costs, and flexibility and reliability of each technology. Moreover, the configurations of the communication system could involve both wireline and wireless technologies at varying degrees.

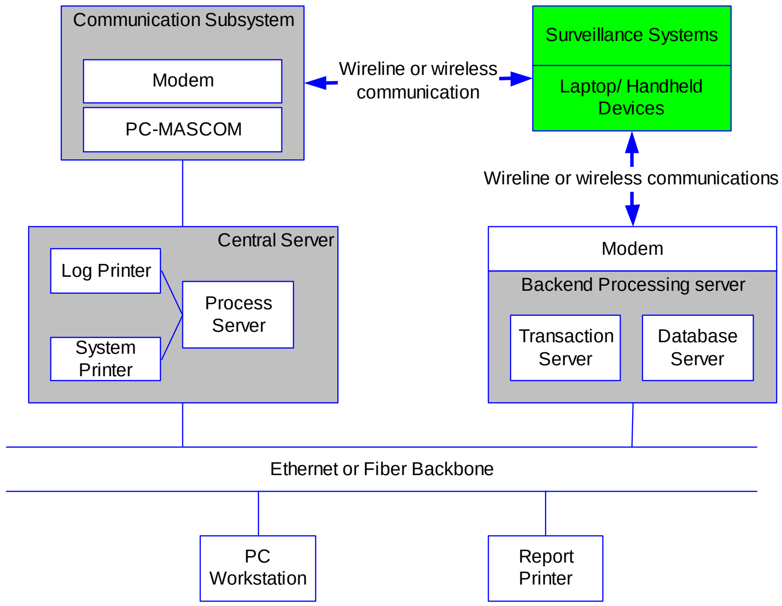

Figure 2-1. Typical communications between surveillance systems and TMC servers.

A particular example is the "ITS Nodes" architecture, which was implemented in the Amarillo district in 2002. This could become Texas' model for rural ITS systems. The concept, design, and implementation of the ITS nodes are briefly discussed in this section.

The Texas Department of Transportation (TxDOT) has begun deployment of the first phase of a combined traffic management and traveler information system in its Amarillo district that, in later phases, could become a model for rural ITS deployments elsewhere in the state. While the initial phase of deployment is quite conventional, involving remote cameras and dynamic message signs (DMS), Phase 2—which could start as early as spring 2003—will involve the deployment of numerous "rural ITS nodes." One of objective of the system is to advise travelers—especially long-haul truckers—about road conditions many miles ahead, so that they can determine their own route changes in order to bypass serious weather-related conditions.

The Amarillo district, in the far northwest "Panhandle" region of Texas, faces frequent severe ice and snow conditions during the winter. Interstate 40, which runs through the city of Amarillo, is a gateway to the West for travelers from both Oklahoma and Texas, especially long-haul truckers.

The first phase of deployment, which is currently underway (see Figure 2–2), includes cameras and dynamic message signs on I-40 as well as other major state highways. A new traffic management center (TMC) will be built this winter at the TxDOT Amarillo district office and should be operational by January or February 2004.

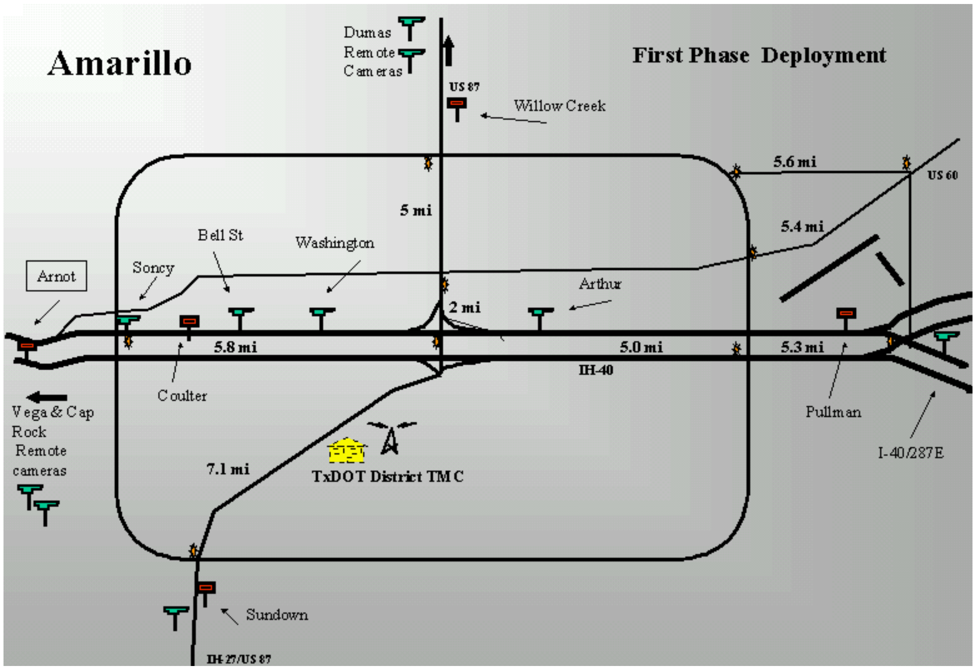

Figure 2-2. Amarillo rural ITS system (TxDOT).

Communication between these nodes and the new Amarillo TMC—especially those nodes not located on I-40—would initially take place via telephone lines, including Integrated Services Digital Network (ISDN) lines when available. High-speed wireline networks are typically not available in rural areas. ISDN phone lines typically support frame rates of 10–12 frames per second from the remote cameras. Wireless technologies could be a good alternative for this application (Figure 2-3).

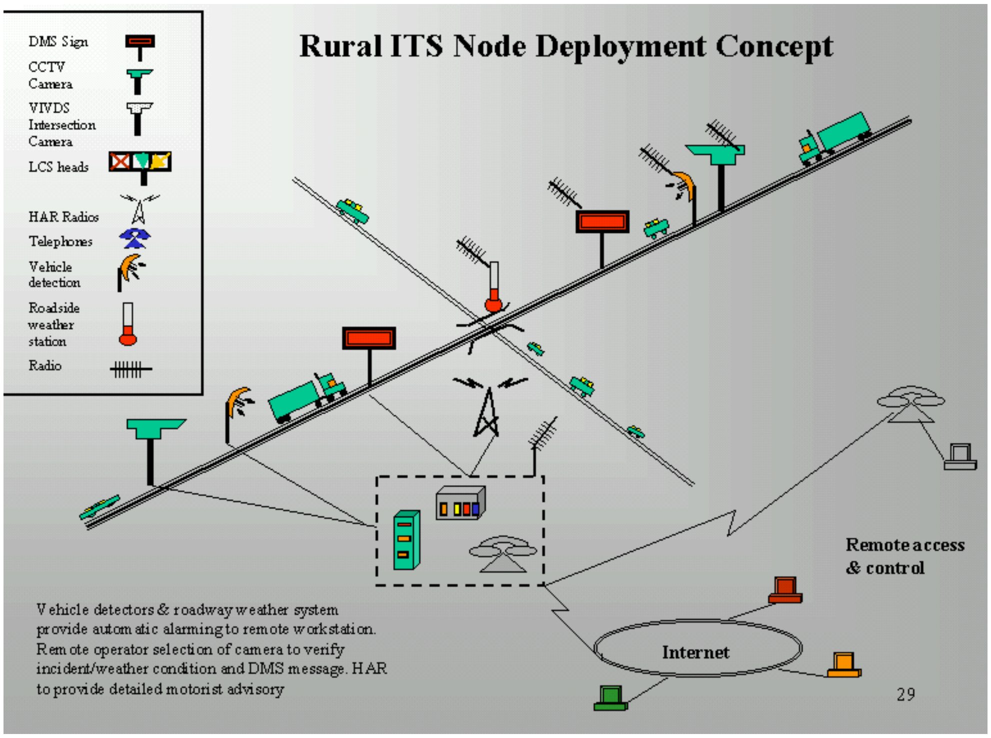

Figure 2-3. Rural ITS node deployment concept.

It is expected that the ITS node concept will catch on elsewhere in Texas because there are a number of remote spots in the district where some kind of surveillance or controls are needed. The node concept would work well for smaller towns where a full-blown traffic management system is not in place. Nonetheless, the success of this concept depends on the type of available communication technologies and services. Determining the most cost-effective communication technology remains to be a challenge issue.

2.3. Portable Traffic Management System (PTMS)

Primarily developed for work zone applications, the PTMS usually consists of portable skids that contain a machine vision system, variable message sign (VMS), central processing unit (CPU), and spread spectrum radio communications. The skids are placed in strategic locations in and around the work zone and, when linked to one another by the spread spectrum radio, form nodes in the PTMS network. The nodes can include both vehicle detection devices and driver information devices. MnDOT developed a PTMS to transmit vehicle detection and surveillance data to the traffic control center at the MnDOT Traffic Management Center. Operators use the data to make decisions regarding traffic control that are intended to improve traffic flow through the work zone. The traffic control changes are implemented by relaying messages to the motorist through the driver information subsystem that consists of full-size portable variable message signs and smaller work zone portable variable message signs. The information can also be made available to the public on a World Wide Web page on the Internet (Klein, 1999).

2.4. Rural Smart Work Zone

A rural smart work zone, developed by the Iowa Department of Transportation, was motivated by the experience during the 1997 Interstate-80 reconstruction in Iowa. Traffic engineers acted to mitigate the impact of traffic incidents in the work zone and to reduce the number of secondary traffic accidents. The increased incidents and secondary accidents were caused by reduced work zone capacity, which combined with peak period demand to create traffic backups that brought about the accidents. The rural smart work zone consists of an incident detection unit (IDU) to measure vehicle speed and a camera to acquire images of the traffic flow. When speeds drop below 35 mph (56.3 km/h), the IDU automatically places a series of four cellular telephone calls, three to activate Automated Traveler Information System (ATIS) devices (namely, two mobile changeable message signs [CMS] and a highway advisory radio [HAR]) and one to notify the roving vehicle.

2.5. Commercial Vehicle Operations

An example of using communication technologies in commercial vehicle fleet operation is railroad operation. A technology called mobile LAN was used to provide a single data communication system to unify locomotive health and work order reporting communications. As shown in Figure 2–4, as locomotives move, the system seamlessly switches among the available communications media using a least-cost routing algorithm, thereby reducing the cost of communication. When the switchman is working away from the locomotive, he uses a hand-held computer that communicates to the locomotive system over a spread spectrum radio link. Messages are passed through the communications system on the locomotive to the railroad mainframe. Work order events are reported more quickly since switchmen report them as they occur with a hand-held device. This integrated approach allows operators to leverage existing capital investments while gaining extended coverage through satellite communications.

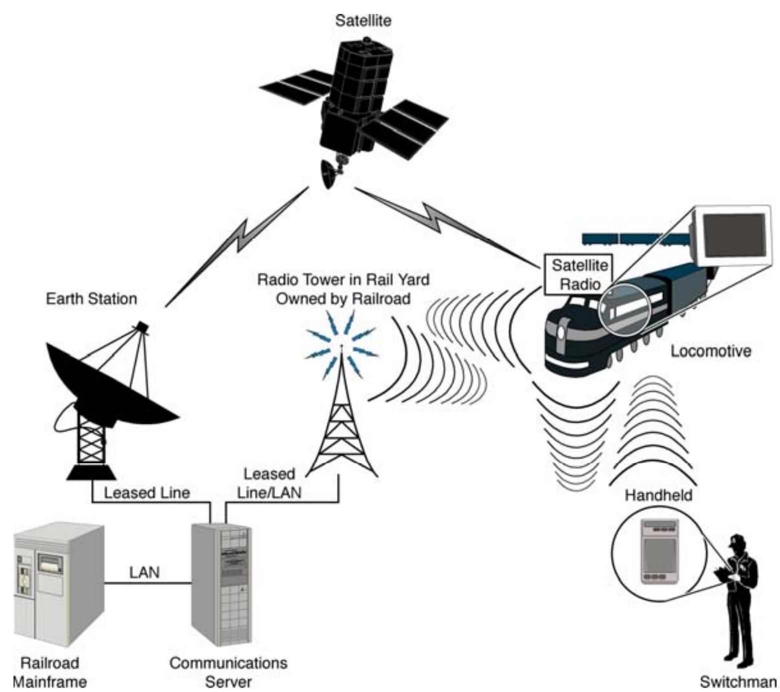

Figure 2-4. Communication technology used in commercial vehicle operation – an example in railroad management (SAIC, 2002).

2.6. Emergency Response Management

Interjurisdictional information sharing and coordination are regularly exercised in areas of emergency management and have gained added significance in conjunction with homeland security concerns. As defined by the Texas Department of Public Safety (DPS), each county has a division of emergency management that is responsible for coordinating disaster planning for all entities within the county. This includes the preparation and annual review of the emergency management plan and exercising emergency response during major disasters.

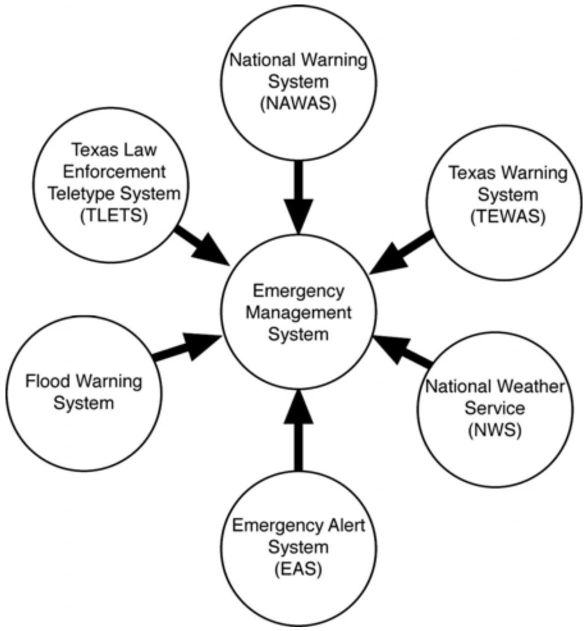

Figure 2-5. Emergency Management System in Texas.

As shown in Figure 2–5, the emergency management system defined above includes the following agencies:

National Warning Systems—NAWAS is a nationwide dedicated telephone warning system. It operates on three levels: federal, state, and local. When North American Aerospace Defense (NORAD) confirms an enemy attack, a warning is disseminated to all warning points on the system. The primary warning point for NAWAS is the DPS area warning center in Austin.

Texas Warning System (TEWAS)—TEWAS is the state-level extension of NAWAS. Each area warning center is on the TEWAS network, along with 23 National Weather Services (NWS) forecast offices and the Department of Energy's Amarillo area office.

Texas Law Enforcement Teletype System (TLETS)—The Texas Law Enforcement Telecommunications System is a statewide telecommunications network connecting the state warning point with approximately 670 city, county, state, federal, and military law enforcement and criminal justice agencies in Texas.

National Weather Service (NWS)—Current weather information and warnings are received over the NWS teletype circuit. Radio broadcasts are received over the weather radio broadcasting out of Houston. In addition, the NWS will issue severe weather warnings over the NAWAS line and the DPS teletype system. Citizens are encouraged to have battery-operated tone alert weather radios in their homes and work areas. These radios may be purchased locally through retail outlets such as Radio Shack.

Flood Warning System—The National Weather Service, the Corps of Engineers, and river authorities have established a network of rain and river flood sensing devices to collect data for flood-warning purposes. If excessive rainfall occurs, the NWS and the River Forecast Center make flood predictions, and, if necessary, warnings are issued.

Emergency Alert System (EAS)—The EAS provides a means for supplying emergency information to the public. It utilizes commercial radio and television broadcast services, which are provided on an organized basis. The system may be activated at the federal, state, or local level.

Communications that take place among the above agencies result from the extensive use of a wide range of communication technology choices, including ground analog radio, cellular network, satellite network, and fiber-optic network.

Chapter 3. A Brief Survey of Emerging Communication Technologies

3.1. Overview of Wireline and Wireless Technologies

Wireline and wireless communication technologies continue to be innovated at an explosive rate. Old technologies, although slow, low-bandwidth, and medium-dependent, tend to be robust and resilient to various environmental conditions. Newer technologies generally offer much higher data throughput, break the barriers of communication media, and provide flexible configurations and a wide range of services.

Wireline communication technologies, developed much earlier than wireless technologies, offer services that allow for various data, voice, and video applications. New communication protocol and materials continue to increase the throughput of data that run through traditional media like copper wires or coaxial cables. As shown in Table 3–1, various technologies offer transmission rates ranging from tens bps (twisted pair copper) to tens Gbps (fiber optics). Technologies that hybridize various media (e.g., Asymmetric Digital Subscriber Line [ADSL] using copper wire and satellite) could improve the service, data rate, and configuration flexibility. The upcoming new technology in wireline communication is the use of power lines not only to transmit electricity but also to deliver data, voice, and videos.

Wireless communication technologies have been advancing at an exponential rate over the past decade. Using air as the primary transmission medium, wireless communications can take place under almost any conditions by using appropriate technologies. As such, wireless technologies have been increasingly used in various ITS and transportation operation applications. Figure 3–1 shows the communication architecture and techniques used during the Mobile Surveillance and Wireless Communication Systems Field Operational Test (Klein, 1999). In the field operational test, the spread spectrum radio was used to provide direct links between the surveillance trailers and relay sites, and among the relay site, the district office, the TMC, and the research laboratory.

Table 3-1. Wireline technology characteristics

Existing Technologies	
Twisted-pair	• Medium – copper wire • Operates at 300 to 3,00 Hz • Offers 56 bps with range 9 to 15 miles • Support data, voice, slow scan TV
ISDN	• Offers 64 kbps
ADSL (copper wire)	• Offers 1.5 Mbps to 6.3 Mbps downstream, depending on wire gauge, protocol, and distance • Support data, voice and video
ADSL (copper wire + satellite)	• Offers 1.5 Mbps downstream, 128 kbps upstream • Support data, voice and video
Cable	• Medium – coaxial cable • Operates at 5 to 350 MHz • Offers 10 Mbps downstream, 1.5 Mbps to 10 Mbps upstream • Support data, voice and video

Existing Technologies	
Fiber-optics	• Medium – fiber glass • Operates using laser waves • Offers from 10 Mbps to 10s Gbps • Support data, voice and video, usually used in backbone network, now increasing used at access network
Upcoming Technologies	
Power Line	• Medium – electricity power line • Offers up to 15 Mbps data transfer rate • Latest standard released in 2002 • Field test in 2002 (Homeplug, 2002)

Sources: Federal Highway Administration, 1996; Homeplug Network Alliance, 2002.

A partial list of commonly available wireless technologies is discussed below. Detailed discussions of specific wireless technologies are given in Section 3.2.

Circuit-switched data are already available across existing analog and digital cellular networks worldwide for a decade. Packet-switched data services are also available in several countries over dedicated frequency bands through BellSouth Wireless Data (formerly known as RAM Mobile Data before BellSouth acquired it) and ARDIS over Cellular Digital Packet Data (CDPD) networks. Other standards (e.g., pACT and iDEN) have been propagated into various wireless data markets in many geographical areas. A number of telecommunications companies have deployed circuit-switched CDPD for a decade, allowing cellular operators to cost-effectively offer data service where voice services already exist. Most U.S. carriers have already adopted CDPD, and some carriers, such as Ameritech and Bell Atlantic NYNEX, have linked their CDPD networks to offer seamless roaming coverage throughout their service areas. Canada, Mexico, and New Zealand, along with several other countries, are also rolling out CDPD systems. CDPD is expected to phase out of marketing by 2005 (for further discussion see Sections 3.2, 4.1, and 4.2).

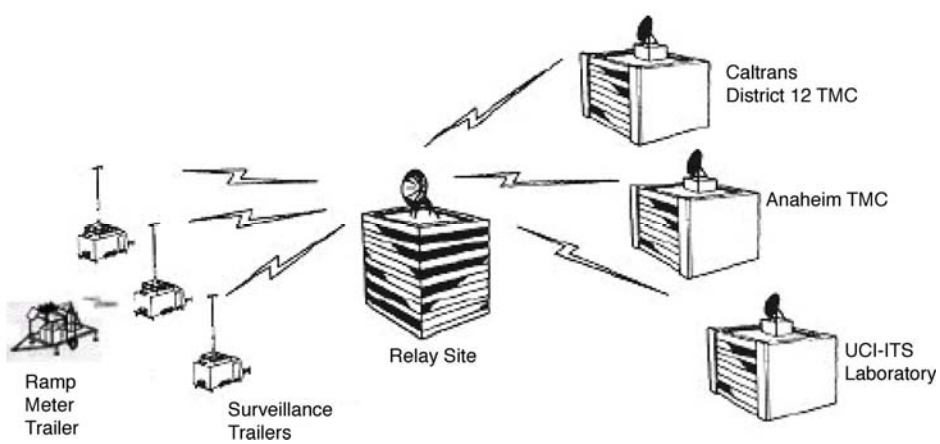

Figure 3-1. Transmission of video and data among trailers, relay site, TMCs, and UCI during the mobile surveillance and wireless communication systems field operational test (Klein, 1999).

Fixed wireless technology (including radio spectrum, spread spectrum, microwave, local multipoint distribution service, and multi-channel multipoint distribution service), as Figure 3–2 shows, can have a maximum wide area range of up to 50 kilometers between radio transceivers, but that drops to 1,200 feet or less in in-building systems, such as wireless local area networks (WLANs) accessed through laptop computers equipped with WLAN cards.

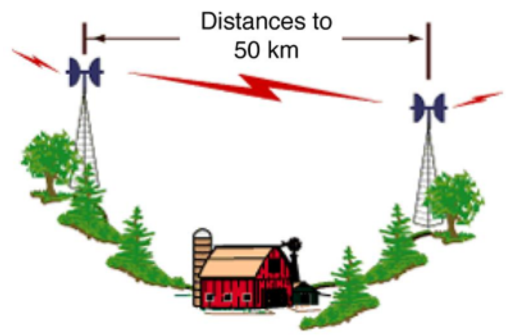

Figure 3-2. Maximum distance between base stations for fixed wireless technology (Rysavy, 2002).

Microwave communications, including analog and digital point-to-point communications, can replace leased lines in dedicated networks with wide area coverage up to 50 miles.

Paging is now available with one- or two-way service and 100% coverage in the United States and most other countries. Service is available from a variety of carriers, including certain FM broadcasters and mobile communications satellite services.

Integrated Digital Enhanced Network, better known as iDEN, essentially boosts the performance of cellular networks to combine voice, dispatch, and short messaging with data. Developed by Motorola, iDEN covers most U.S. metropolitan areas.

Satellites, whether in geostationary earth orbit (GEO) or medium- or low-earth orbit (MEO and LEO), offer global data coverage with data rates ranging from 56 Kbps to 155 Mbps. Figure 3–3 provides a quick overview of the various wireless technologies that operate at three distinct altitudes.

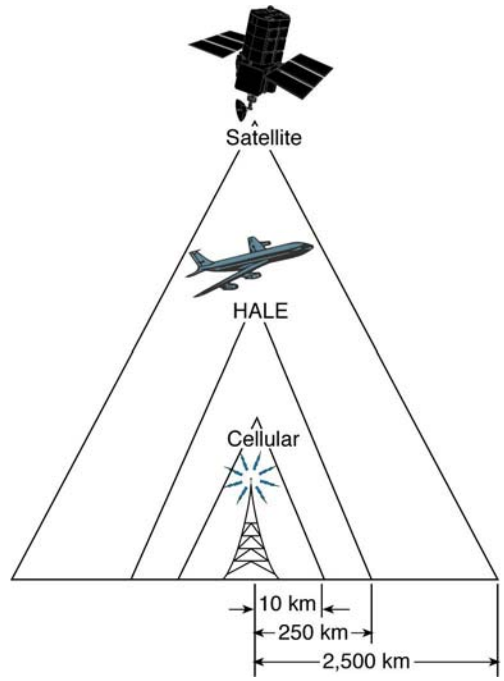

Figure 3-3. Service range of three types of wireless communication technologies (Rysavy, 2002).

Table 3-2. Wireless technology characteristics

Existing Technologies	
Cellular	• Data transfer speeds of 9.6 kbps at 2G, can go up to 50 – 70 Kbps with 144 kbps peak rate at 3G • Digital airtime rate cheaper than analog charges • Does not reach beyond suburban areas • Cellular digital packet data (CDPD) supports data transfer rate as high as 19.2 kbps. The data rate will be improved significantly by the 3G technology • Personal communication service (PCS) user greatly reduced transmitter power so phones are smaller, lighter and able to operate loner on a single charge – operate mostly along major travel corridors
Radiopaging	• Primarily an urban service • Traditionally just a one-way service • Simple technology • Competition among providers is creating a wide selection of options for users • Tone and voice message models are available
Land Mobile Radio	• Less high-tech than other wireless services for voice communication • Has existed for almost 40 years • Rugged, dependable, proven • Low airtime costs, with set-aside frequencies • Only by switching to a digital data transmission could call scanning be eliminated
Radio Data Network (RDN)	• RDN cannot carry voice communications • Provides mobile data networking at fairly slow data transmission speeds • Very limited coverage into rural locations • Airtime rates difficult to calculate and modems are expensive
Micro-Cellular	• Another version of RDN • Uses spread-spectrum transmission (unlicensed frequencies between 902-928 MHz) • Faster data transfer rate (up to 77 kbps) than standard RDN • May be susceptible to interference problems because of sharing frequencies • Lower equipment and airtime rates than standard RDN
Microwave	• Ideal for transmission of large quantities of voice, data or video • Less microwave congestion outside metropolitan areas • Microwave requires clear link-of-sight between sending and receiving antennas • Most operate at 25-mile distances between transmission towers • Transmission is very reliable and secured because their use licensed • Service can be leased from many common carriers
Spread Spectrum	• Alternative to Microwave • Offer rates of 1, 2, 3, 4 and 10 or 11 Mbps • Distance up to 10 or 25 miles

Table 3-2., continued.

Existing Technology	
Satellites	• Geostationary satellites (about 22,300 mile high) offer wide coverage, but airtime is expensive • Geostationary satellites offer high-quality and service reliability for voice communication • Newly emerging Low Earth Orbit (LEO) satellites (about 500 miles high) offer less interference and much cheaper airtime than fixed satellites • Handsets for low earth orbit satellite communication requires less power, but continuous coverage requires more satellites to be deployed; estimated 1,700 additional LEO satellite by 2005 • Offers rate at 56 Kbps to 155 Mbps
Upcoming Technologies	
3 G Cellular	• Offers 384 kbps peak
Mutlichannel Multipoint Distribution Service (MMDS)	• Point-to-multipoint service intended for video • Operates at 2.5 GHz with range of about 30 miles • Operate at very high frequency (27.5 GHz to 31.3 GHz) • Offer rates at 10 Mbps
Local Multipoint Distribution Service (LMDS)	• Point-to-multipoint with centralized hubs communicating to fixed-antenna and radios in a small range (3 miles) • Operate at very high frequency (27.5 GHz to 31.3 GHz) • Offer rates at 10 Mbps

Sources: Pietrzyk, 2000; Rysavy, 2002; Bates, 2000; Schneiderman, 1999.

The cost for different communication technologies varies widely, from hundreds of dollars for a GPRS PC card to at least $2,500 for a mobile satellite terminal. Service charges may vary just as widely. A partial list of comparing several communication technologies (Pietrzyk, 2000) shows the complexity of choosing appropriate technologies given wide variations in cost, available bandwidth, and reliability.

Such complexity motivated the need for an effective and systematic approach and guidelines to facilitate choosing appropriate communication technologies for traffic operations applications, taking into account practical constraints and cost factors.

3.2. Emerging Wireless Technologies

3.2.1. 802.11g (Wi-Fi)

3.2.1.1. Technology Overview

The new IEEE standard 802.11g raises the data rate of the most widely used wireless local area network technology 802.11b to 54 Mbps from 11 Mbps. The two standards operate in the 2.4 GHz frequency range and can co-exist in the same network, even though 802.11g uses orthogonal frequency division multiplexing (OFDM) technology and 802.11b uses direct sequence spread spectrum (DSSS) technique. This new standard provides optional backward compatibility with 802.11b.

The theoretical data speeds of 54 Mbps for 802.11g and 11 Mbps for 802.11b do not really reflect the data throughput achieved in real time. In 802.11b the real-time data rate is more like 5.5 Mbps as the rest of the bandwidth accounts for the system overhead. Still, the data rates for 802.11g are around three to five times higher and appear very fast compared with 802.11b. The added transmission speed gives wireless networks based on IEEE 802.11b (often called Wi-Fi) the ability to serve as many as four to five times more users than they do now. It also opens the possibility for using IEEE 802.11 networks in more demanding applications, such as wireless multimedia video transmission and broadcast MPEG.

The data speed of 802.11g access points falls back to a speed of 802.11b if there are any 802.11b components present in its local area network (LAN). For optimum performance in data speed, it requires the usage of 802.11g in the single mode instead of the dual-mode 802.11b/g.[1],[2]

The 802.11 LANs are built around cells called basic service sets. The base station in each cell is called an access point. Laptop computers, field sensors, and other devices communicate via the access point using small wireless LAN cards.

3.2.1.2. Applications/Vendors

The applications of 802.11g in intelligent transportation systems include:

California Department of Transportation (Caltrans) is currently testing Wi-Fi for public access on its Capitol Corridor Intercity train route in California for a three-month period.[3] This can be extended to automobiles to provide data services such as traveler information and traffic congestion to the motorists.

In January 2000 WiLAN in partnership with California Department of Transportation (Caltrans) demonstrated support of 20 Mbps data services to a vehicle moving at 70 mph over a 1.3-mile stretch of US Highway 101 in Goleta, California.

Some of the applications of this technology are adaptive traffic signals, variable message boards, surveillance video cameras, etc.

This technology is ideal for short-range wireless communication where high bandwidth is required, like establishing a wireless data link among unattended ground sensors and between remote video cameras and roadside control units.

802.11 are widely used in building-to-building data communication using wireless LAN bridges. Wireless LAN bridges provide an alternative to more expensive leased lines and underground cabling projects.

3.2.1.3. Latest Product/Technology Developments

Airgo Networks, a developer of innovative wireless technology and products, is currently testing an AGN100 chipset, which it claims extends the existing Wi-Fi data rates to 108 Mbps per channel and is compatible with all common Wi-Fi standards. The AGN100 chipset greatly increases the throughput, range, and reliability of Wi-Fi devices by utilizing Airgo's breakthrough multi-antenna transmission and reception technology. It incorporates the multiple-input-multiple-output (MIMO) technology that is the most sophisticated and highest-performance class of smart antenna signal processing.[4]

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[1] http://standards.ieee.org/announcements/80211gfinal.html
[2] http://www.nwfusion.com/reviews/2003/0512rev11gside2.html
[3] http://www.nwfusion.com/news/2003/0815transport.html
[4] http://www.airgonetworks.com/AirgoLaunchRelease.doc

D-Link Systems and Texas Instruments (TI) will be launching a new family of 802.11g+ products by late third quarter of 2003. The new D-Link AirPlus Extreme G+ product family based on the TI TNETW1130 chipset will deliver high-speed throughput, an improvement of up to 8 times the 802.11b average throughputs. TI's 802.11g+ solution is optimized to deliver the highest performance and interoperability in any 802.11g or 802.11b network.[5]

Dedicated Short Range Communications (DSRC) – The DSRC standards committee chose the wireless LAN standard 802.11a as the link for vehicle-powered, high-speed wireless two-way communication. Current DSRC systems such as toll tags operate in the 900 MHz spectrum, but no single standard was established, and several proprietary systems were deployed. Hence the need for a DSRC standard for all vehicles to be able to communicate with each other. The new generation of DSRC is a vehicle-powered two-way communication link, with data rates ranging from 6 to 27 Mbps. Some of the future probabilistic intelligent transportation applications are:

> *Emergency Vehicle Warning* – With DSRC an emergency vehicle can have the traffic system change traffic lights to clear traffic along its intended route. Also, this route information can be broadcast to other cars to provide users/vehicles with specific directions to reduce collisions.
>
> *Traffic Congestion Data* – The oncoming traffic exchanges information on the traffic status ahead so that the vehicle navigation systems can dynamically provide the best route to a destination. This can be done by a software application integrated into the automobile navigation system.
>
> Because of the radios that will be installed operate in both DSRC and UNII bands, plenty of 802.11 hotspots at various locations will be needed to provide vehicles with location-specific travel information services along with many other services.[6]

Mesh networks routing technologies patented by Mesh Networks can be used over the 802.11g standards to greatly increase the throughput of the network and overcome situations where line of sight is difficult, which is a serious limitation of 802.11 systems. The range between the communication devices can also be increased.

3.2.1.4. *Case Study and Analysis*

Wireless LAN Bridge — It is an extension point for the wireless network. A wireless LAN bridge connected to the network at one location can transmit and receive data from another bridge in another location. Wireless LAN bridges support fairly high data rates and ranges of several miles with the use of line-of-sight directional antennas. A unidirectional antenna can narrow the overall beam width of the base station, increasing the range. A narrow beam antenna enables us to transmit many times the distance of our base station's omnidirectional antenna's range, albeit in just one or

[5] http://www.80211gnews.com/publications/page354-547681.asp
[6] http://www.wi-fiplanet.com/columns/article.php/1005771

two directions. This results in an increased range, but reduces our mobility as the transmissions have narrower directional coverage. We can also improve the range by avoiding electrical appliances that emit interfering radio waves, since they operate in the same frequency range of 2.4 GHz. It is also possible to change the Wi-Fi network channel to avoid the interfering channels used by the competing devices. In addition, various Wi-Fi products have proprietary solutions to help reduce interference.[7]

In April 2001 the Michigan Department of Transportation (MDOT) began a five-month project to repair and rehabilitate I-496 that runs through the city of Lansing. To avoid inconvenience to motorists, MDOT contracted AVD Technologies, an audio, video, and data integration company, to erect cameras and provide radar detectors at various locations along I-496. Advanced wireless bridges from WiLAN, were placed at various locations along I-496 to provide wireless links with the video cameras. The real-time images from the cameras were transmitted using these wireless bridges to a central monitoring station where AVD observed the congestion on I-496 and reported it to MDOT. MDOT then used this information on short message signs that instantly update the motorists on upcoming congestion and alternate routes they can take to avoid it.[8]

3.2.2. General Packet Radio Service

3.2.2.1. Technology Overview

General Packet Radio Service (GPRS) is a wireless technology standard, generally dubbed as 2.5G, that supports fast point-to-point communication through devices that enable an "always on" Internet connection. GPRS facilitates instant connections whereby information can be sent or received immediately as the need arises, subject to radio coverage.[9]

GPRS technology converts wireless data into standard Internet packets, enabling interoperability between the Internet and the GSM network. The data to be transmitted are split into separate but related packets before being transmitted and reassembled at the receiving end.

The theoretical data speeds are as high as 171.2 Kbps. The data rates from 9 to 100 Kbps can be achieved by assigning multiple time slots per frame to the same user. The use of packet switching in GPRS technology optimizes the data network capacity by using the bandwidth only when necessary. Rather than dedicating a radio channel to a data user for a fixed period of time, the available radio resource can be concurrently shared between several users. This efficient use of radio resources means that large numbers of GPRS users can potentially share the same bandwidth and be served from a single cell.

GPRS supports both Global System for Mobile communications (GSM) and the IS-136 Time Division Multiple Access (TDMA) standard networks.[10]

3.2.3. Multi-Code Direct Sequence Spread Spectrum Technology (MC-DSSS)

3.2.3.1. Technology Overview

Spread spectrum techniques were originally developed for military applications to provide secure communication channels impervious to enemy jamming. Frequency bands 902-928 MHz, 2.4-2.484

[7] http://www.weca.net/OpenSection/range.asp?TID=2#walls
[8] http://www.wilan.com/success/index.html
[9] http://www.itsa.org/ITSNEWS.NSF/0/118b6014e357788a85256c440006600a?OpenDocument
[10] http://www.gsmworld.com/technology/gprs/intro.shtml#1

GHz, and 5.725-5.85 GHz are available for unlicensed spread spectrum transmission. As its name implies, the spread spectrum signal is spread across a larger bandwidth than the minimum required to transmit the data successfully.

The two most popular spread spectrum techniques used are:

- direct sequence spread spectrum (DSSS)
- frequency hopping spread spectrum (FHSS)

WiLAN, Inc. patented multi-code direct sequence spread spectrum (MC-DSSS) technology using direct sequence spread spectrum (DSSS) techniques that increases the carrying capacity of traditional spread spectrum systems by up to a factor of ten.

MC-DSSS is a spectrally efficient spread spectrum modulation technique. This technique enables multiple CDMA codes to be assigned to a single user in a CDMA network, thus increasing the throughput. MC-DSSS is used in WiLAN's advanced Ethernet bridges, which operate in the 2.4–2.4835 GHz frequency range supporting up to 7 channels. The data transmission rate varies from 3.4 Mbps to 9 Mbps as the number of remotes per base station varies from 255 to 1000. Point-to-multipoint network topology has a transmission distance of up to 10 km and up to 40km for a point-to-point transmission.[11]

3.2.3.2. Applications/Vendors

The applications of MC-DSSS products in intelligent transportation systems include the following: AVD Technologies used WiLAN's advanced Ethernet bridges to establish a wireless network for streaming real-time video from the cameras on the highway to monitor traffic congestion and provide the motorists with up-to-the-minute updates on problem spots and alternative routes off of the freeway.[12]

3.2.3.3. Latest Product/Technology Developments

WiLAN filed an intellectual property (IP) statement in 1999 with the International Telecommunication Union (ITU) offering to make MC-DSSS available for licensing on fair, reasonable, and non-discriminatory terms. This statement is based on the company's belief that the IMT-2000 proposals under consideration for 3G standards use MC-DSSS technology. The ITU received ten proposals for 3G systems, with most of them based on CDMA.[13]

3.2.3.4. Case Study and Analysis

In April 2001 the Michigan Department of Transportation (MDOT) began a five-month project to repair and rehabilitate I-496 that runs through the city of Lansing. To avoid inconvenience to motorists, MDOT contracted AVD Technologies, an audio, video, and data integration company to erect cameras and provide radar detectors at various locations along I-496. Advanced wireless bridges from WiLAN, Inc were placed at various locations along I-496 to provide wireless links with the video cameras. The real-time images from the cameras were transmitted using these wireless bridges to a central monitoring station where AVD observed the congestion on I-496 and reported it

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[11] http://www.wilan.com/
[12] http://www.wilan.com/
[13] http://www.wilan.com/

to MDOT. The MDOT then used this information on short message signs that instantly update the motorists on upcoming congestion and alternate routes that they can take to avoid it.

3.2.4. Wide-Band Orthogonal Frequency Division Multiplexing

3.2.4.1. Technology Overview

Wide-band orthogonal frequency division multiplexing (W-OFDM) uses the IEEE wireless standards 802.11a and 802.11g as its basis. It is also the foundation for the proposed IEEE standard 802.16. WiLAN patented this technology in the United States and Canada. This transmission scheme enables data to be encoded on multiple high-speed radio frequencies concurrently, which results in greater security, increased amounts of data being sent, and the efficient use of the bandwidth. W-OFDM is a non-line of sight technology with multilayered security.

W-OFDM enables the implementation of low power multipoint RF networks that minimize interference with adjacent networks. This reduced interference enables independent channels to operate within the same band allowing multipoint networks and point-to-point backbone systems to be overlaid in the same frequency band.[14]

The W-OFDM channels are 6 MHz wide and can support raw data rates up to 19 Mbps. The W-OFDM system uses Reed Solomon encoding. The modulation scheme is 16-ary quadrature amplitude modulation. Another feature of WiLAN's W-OFDM system is the use of signal whitening that enables security implementation into the system.[15]

The latest wireless access product LIBRA 5800 from WiLAN operating in the 5.8 GHz frequency range provides a data rate of 32 Mbps in narrow 10 MHz channels and a range of up to 41 miles in a point-to-point configuration, or an aggregated data rate of up to 192 Mbps per six sector cell and a radius of up to 22 miles in a point-to-multipoint configuration. According to the President and COO of WiLAN LIBRA is the only product that uses 256-carrier W-OFDM specifically designed for outdoor wireless metropolitan area network (WMAN) applications.[16]

3.2.4.2. Applications/Vendors

The applications of W-OFDM technology in intelligent transportation systems include: some of the applications are controlling traffic signals remotely, vehicular traffic monitoring, and providing public transportation information and other data services to motorists.

3.2.4.3. Latest Product/Technology Developments

There has been speculation that OFDM will be the ideal technology for a fourth-generation cellular network. AT&T has entered into a contract with Nortel Networks to develop a 4G standard based on its existing Angel product. The downlink in such a system would be OFDM, which is capable of transmitting data to the phones at speeds of 10 Mbps; the uplink back to the base stations would be a higher speed time-division multiple-access link.

Wellink, a leading provider of high-speed telecommunications systems, and WiLAN, a global provider of broadband wireless communication products and technologies, have reached an

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[14] http://www.wilan.com/technology/index.html
[15] http://www.commsdesign.com/design_corner/OEG20010227S0025
[16] http://www.80211gnews.com/publications/page354-525711.asp

agreement to develop mobile wireless products based on WiLAN's W-OFDM technology. These mobile wireless systems are initially intended Intelligent Transportation Systems (ITS). ITS applications may include real-time video security, advertising, and Internet.[17]

3.2.4.4. Case Study and Analysis

W-OFDM is a variant of the Orthogonal Frequency Division Multiplexing (OFDM) technology that improves its characteristics. OFDM technology has been around since the 1960s. WiLAN developed W-OFDM technology in the early 1990s. The reason that the OFDM and W-OFDM technologies are becoming popular now is because economical integrated circuits that can perform a high-speed FFT in real time were not available till 1998.[18]

Caltrans, the California Department of Transportation has hosted a demonstration of WiLAN's first mobile application of W-OFDM technology in the year 1999. It was held on Highway 101 in Santa Barbara. The high-speed demonstration proved successful as video streaming and file transfers were exchanged between two I.WILL 300-24 access points at a data rate of 30 Mbps. One access point was located in a traffic cabinet on Highway 101, transmitting to another access point in a moving vehicle while traveling at speeds of up to 70 miles per hour.[19]

3.2.5. 3G Cellular Wireless

There are currently two main standards in the 3rd generation (3G) cellular network: the European-company–backed WCDMA and the U.S.-company–backed CDMA2000. Apparently, the WCDMA standard will provide natural migration for those operators who are currently using the Global Systems for Mobile communications (GSM), and the U. S. market will likely be dominated by the CDMA2000 standard.

GSM is a 2nd generation digital cellular telecommunication standard widely implemented in many countries. This standard is based on the time division multiple access (TDMA) protocol, where several different calls may share the same carrier with each call assigned a separate time slot. The frequency range specified for GSM networks is 1.850 MHz to 1.990 MHz, with a bandwidth specification of 270 Kbps. Circuit switched data are possible at either 9.6 or 14.4 Kbps.[20] The enhanced data rate for GSM evolution (EDGE) is an extension of the current 2.5G digital technologies, such as GSM-based GPRS and CDMA-based 1xRTT, that provide higher data rates with existing systems. EDGE uses 8-PSK (phase shift keying) modulation to provide up to three times the data rate in a GPRS system. EDGE enables a maximum theoretical data speed of up to 513 Kbps, but the actual data rate is 60 to 120 Kbps. This enables voice, data, and video streaming.[21] Existing GSM operators in the United States include Cingular Wireless and AT&T Wireless.

Code division multiple access (CDMA) is a form of spread spectrum developed for commercial use by Qualcomm. CDMA2000 is a third generation technology that evolved from CDMA, and it has two phases, 1x and 3x. 1xRTT stands for 1 channel (1.25 MHz) radio transmission technology. The maximum theoretical data speed in the forward direction from the base station to the mobile is 307.2 Kbps and 144 Kbps in the reverse direction. The Telecommunication Industries Association (TIA) is working on a second release of this protocol to support downlink speeds of 614 Kbps. But the actual

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[17] http://www.wi-lan.com/news/press290.html
[18] http://www.wilan.com/technology/index.html
[19] http://www.wi-lan.com/news/press78.html
[20] http://www.iec.org/online/tutorials/gsm/
[21] http://press.nokia.com/PR/200212/883986_5.html

data rates are lower, depending on the user channel quality and some other factors. The current implementation involves voice and data services. A sustainable data rate of around 40 Kbps in the reverse direction will support video at frames rates between 5 and 20 frames per second. The forerunner of the CDMA2000-based network is Verizon Network.

3xRTT is the future implementation of the 3x phase of CDMA2000, where three 1xRTT channels are multiplexed in a 5 MHz channel. It supports all channels sizes, which are multiples of 5 MHz, and is envisioned to enable data rates of up to 2 Mbps.

CDMA2000 1xEV-DO stands for 1-channel (1.25 MHz) evolutionary data-only service. This is considered a true 3G service, with peak data rates of up to 2.4 Mbps in the forward direction and 153.5 kbps in the reverse direction. The high data rates also use smaller spreading factors and multilevel modulations. This incorporates burst mode on the forward link with burst rates of 600-1200 Kbps per subscriber.[22] Verizon Network has recently announced its 1xEV-DO service in San Diego and Washington, D.C., in late 2003. The coverage is expected to continue to increase. It is also anticipated that by 2005, 80% of the U.S. network shall be covered by 3G networks. It is anticipated that existing operators who use different standards (GSM versus CDMA) will migrate to respective 3G standards.

Table 3-3. Typical data rates from different cellular standards.

Cellular Family	Generation	Standard	Peak Data Rate (kbits/s)	Typical real life data rate (kbits/s)	Connection type	Modulation
GSM	2-2.5	GSM-CSD (normal)	9.6 / 14.4	9.6	Circuit	GMSK
		HSCSD	28.8 / 43.2	28.8	Circuit	GMSK
		GPRS	115 / 171	50	Packet	GMSK
		EDGE	384 / 513	115	Packet	8-PSK
UMTS	3	FDD	384 / 2000	144	Packet	QPSK
		TDD	384 / 2000	144	Packet	QPSK
CDMAone	2	IS-95A	14.4	14.4	Circuit	QPSK
		IS-95B	64 / 115	56	Packet	QPSK
CDMA 2000	3	1X	144 / 307	130	Packet	QPSK
		1X-EV	2000	tba	Packet	QPSK
		1X-EVDO	2400	tba	Packet	QPSK
TDMA	2	CSD	9.6	9.6	Circuit	DQpi/4PSK

3.2.6. Multihopping Technology

3.2.6.1. Technology Overview

Multihopping technology was developed and patented by Mesh Networks. Mesh Networks created MeshLAN using its patented multihopping technology to extend the coverage, capacity, and throughput of traditional 802.11 networks while reducing the deployment costs. MeshLAN is a complete standards-based 802.11b solution, which significantly increases the value and utility of wireless local area networks (WLAN).

[22] http://www.mitretek.org/publications/its/MP2003V2_05.doc

The multihopping routing technology turns every client device into a router/repeater, so every user improves network coverage and increases network throughput. MeshLAN users can hop through other users or wireless routers in either infrastructure or peer-to-peer mode, greatly enhancing the utility of wireless networking. This enables the users to hop long distances and around obstacles to reach an access point. Hence, this technology overcomes the problem of line of sight in certain situations where it is difficult to have a clear line of sight, a serious limitation in 802.11 systems.

MeshLAN networks are self-forming, that is, they automatically discover neighboring devices and form a robust multihopping network. MeshLAN networks are also self-healing, adjusting the routing configuration, when necessary, to compensate for network congestion and node failures.

The products using this technology greatly increase the coverage of the networks. The data rates range from 1.5 to 6 Mbps. This technology, used with QDMA radios of mesh networks, has been successfully applied to industry standard 802.11b to develop MeshLAN multihopping 802.11b products. This technology can also be applied to other modulation schemes and radios, including 802.11a and g, ultra wideband, WCDMA, and OFDM to increase the product capabilities.

MeshLAN utilizes 802.11b (Wi-Fi) standard-based radios and personal client cards, which can be configured to operate in either MeshLAN enhanced or conventional 802.11b networks.[23]

3.2.6.2. Applications/Vendors

The applications of multihopping technology in intelligent transportation systems include:

Mesh networks can be used in intelligent transportation systems that would utilize dynamic message signs, surveillance cameras, and traffic sensors to help control traffic patterns and ease congestion during peak commute hours.[24]

Mesh networks can be widely used for a number of in-vehicle applications, such as traffic-related safety and location-based services. This can be used economically to have a fixed infrastructure to communicate with remote sensors, traffic lights, or pipeline valves along hundreds of miles.

These networks can be used for location determination in places where GPS satellites cannot penetrate, such as in urban canyons, buildings, tunnels or constructions.[25]

3.2.6.3. Latest Product/Technology Developments

Mesh Networks is currently testing off-the-shelf 802.11 radios and a variant radio it has developed that utilizes real-time equalization and a multitap rake receiver, which can handle multipath and fading to enable multihopping networks at vehicle speeds as fast as 70 mph. In conjunction with relay devices posted on light poles (two per square mile), the system can provide a QoS (Quality of Service) sufficient to stream video and to support VoIP calls. The system has been installed on Orlando, Florida, city buses.[26]

[23] http://www.meshnetworks.com/
[24] http://cooltown.hp.com/mpulse/0603-meshnetworks.asp
[25] http://www.itsa.org/mn.nsf/0/2f4f1ecd1bc8961885256d4700696f42?OpenDocument
[26] http://biz.yahoo.com/bw/030812/125122_1.html

Delphi, a leading automotive electronics vendor, is testing Mesh Networks, p-to-p technology for in-vehicle telematics applications, including streaming environment, web access, safety, and location based services.[27]

Mesh Networks and Viasys reached an agreement to bring this new technology to the Intelligent Transportation systems and Public safety. Viasys, a leading provider of infrastructure development and maintenance services for the transportation industry, will begin offering this Mesh Networks proprietary peer-to-peer technology to its customers.[28]

3.2.6.4. Case Study and Analysis

The low cost and ease of deployment of mobile mesh networking allow public safety agencies to own and operate their own data networks. Mesh networks provides an alternative to the high cost of the cellular data systems for agencies looking for affordable, yet high-performance wireless data replacement CDPD.[29]

[27] http://www.itsa.org/itsnews.nsf/0/24BF8A1A8F40877185256C7D004F2352?OpenDocument
[28] http://www.meshnetworks.com/pages/newsroom/press_releases/release_03_26_03.htm
[29] http://www.itsa.org/mn.nsf/0/2f4f1ecd1bc8961885256d4700696f42?OpenDocument

Table 3-4. Bandwidth, cost, and reliability comparison between communication technologies.

	Medium range data speed (5+ miles)	Medium range data speed (15+ miles)	Full-motion video compatible	Relative cost ($ per bps)	Reliability
Wireline					
Cooper twisted-pair	1.5 Mbps	1.5 Mbps	No	Low	High
Coaxial cable	100 Mbps	100 Mbps	Yes	Medium	Medium
Multi-mode fiber	500 Mbps	N/A	Yes	Low	Very High
Single-mode fiber	40 Gbps	40 Gbps	Yes	Very Low	Very High
Wireless					
Digital microwave	155 Mbps	155 Mbps	Yes	Medium	Medium
Cellular Digital Packet Data	250 kbps	N/A	No	Medium	Medium
Micro-cellular	N/A	N/A	Yes	Low	Medium-High

Source: Pietrzyk, 2000

3.3. Wireless Communication Service Providers

Most of the ILECs (incumbent local exchange carrier, such as Southwestern Bell Company [SBC], or any other bell company), or CLEC (competitive local exchange carrier) which were established after telecommunication deregulation in 1996 provide wireless communication services. There is also an increasing number of such carriers primarily focused on providing wireless services in cities in Texas. As shown in Tables 3–5 and 3–6, there are more than 50 nationwide, regional, or local service providers for wireless communication services in Texas. Most of the nationwide carriers offer both wireless voice and data services using GSM or CDMA technologies. Most of the regional or local providers offer voice services only; several of them offer wireless broadband services, via MMDS or LMDS, or even cellular technology (see Table 3-2). The cost structure for such type of communication service also includes communication devices (e.g., modems) installed on premises, and a monthly service charge. The monthly service charge varies, depending on the data rate and the number of connections required. Some service bundles also include voice and data service. Similar to the wireline communication alternative, the ILEC and CLEC could also provide wireless communication services.

Table 3-5. Nationwide or regional wireless communication service providers in Texas.

Carrier	Coverage Areas
Aeroconnect Wireless	Based in Corpus Christi
Air2LAN Inc	Texas
Alledo Broadband	15 mile radius extending from Alledo, Tx downtown
AllTel	Nationwide
AT&T Wireless	Nationwide
Brazos Cellular	Nationwide
Caprock Cellular	Silverton, Floydada, Matador, Paducah, Ralls, Spur, Gutbrie, Post, Jayton, Aspermont areas in Texas
Cellular One	Nationwide
Cingular Wireless	Nationwide
Digital Cellular of Texas	West Texas
DTN Speednet	Abernathy, Anson, Anton, Archer City, Bridgeport, Brownfield, Buffalo, SpringsLake, Burkburnett, Chillicothe, Crosbyton, Crowell, Dalhar, Goodlet, Hale Center, Hamlin, Hartley, Haskell, Henrietta, Holliday, Idalou, Iowa Park, Knox City, Krum, Lakeside City, Levelland, Littlefield, Munday, Nocona, Nocona Hills, Petersburg, Plainview, Post, Quanah, Ralls, Red Springs, Runaway Bay, Sanger, Seymour, Shallowater, Slaton, Stamford, Vernon, Wolfforth
Edna Online	Edna, Texas.
Leaco Wireless	Most of eastern New Mexico, and parts of West Texas.
Mid-Tex Cellular	Erath, Comanche, Brown, Mills, Coleman, and Runnels counties
New Gen Wireless	Poolville, Peaster, Agnes, Springtown, LaJunta, Azle, Peden, CenterPoint, Briar, Newark, Saginaw, Haslet, Samson , Park, White Settlement, Rhome, Boyd, Paradise, Bridgeport, Decatur
Nextel	Nationwide
People's Wireless	Wood, Rains counties
T-Mobile	Nationwide
TWIN Wireless, Inc	Lower Rio Grande Valley, Texas.
US Cellular	Nationwide
Verizon Wireless	Nationwide
West Central Wireless	Texas
Western Wireless	Amarillo, West Texas, and South East New Mexico
XIT Cellular	Extreme North Western Texas

Table 3-6. Regional or local wireless communication service providers in Texas.

Carrier	Coverage Areas	URL
Aeroconnect Wireless	Based in Corpus Christi	http://www.aeroconnect.net/
Air2LAN Inc	Texas	http://www.air2lan.com/
Alledo Broadband	15 mile radius extending from Alledo, Tx downtown	http://www.aledobroadband.com/
AllTel	Nationwide	http://www.alltel.com/
AT&T Wireless	Nationwide	http://www.attwireless.com/
Brazos Cellular	Nationwide	http://www.brazoscellular.com/
Caprock Cellular	Silverton, Floydada, Matador, Paducah, Ralls, Spur, Gutbrie, Post, Jayton, Aspermont areas in Texas	http://www.caprock-spur.com/
Cellular One	Nationwide	http://www.cellularone.com/
Cingular Wireless	Nationwide	http://www.cingular.com/
Digital Cellular of Texas	West Texas	http://www.digitalcellularoftexas.com/
DTN Speednet	Abernathy, Anson, Anton, Archer City, Bridgeport, Brownfield, Buffalo, SpringsLake, Burkburnett, Chillicothe, Crosbyton, Crowell, Dalhar, Goodlet, Hale Center, Hamlin, Hartley, Haskell, Henrietta, Holliday, Idalou, Iowa Park, Knox City, Krum, Lakeside City, Levelland, Littlefield, Munday, Nocona, Nocona Hills, Petersburg, Plainview, Post, Quanah, Ralls, Red Springs, Runaway Bay, Sanger, Seymour, Shallowater, Slaton, Stamford, Vernon, Wolfforth	http://www.dtnspeed.net/
Edna Online	Edna, Texas.	http://www.ednaonline.com/
Leaco Wireless	Most of eastern New Mexico, and parts of West Texas.	http://www.leaco.net/
Mid-Tex Cellular	Erath, Comanche, Brown, Mills, Coleman, and Runnels counties	http://www.mid-texcellular.com/
New Gen Wireless	Poolville, Peaster, Agnes, Springtown, LaJunta, Azle, Peden, CenterPoint, Briar, Newark, Saginaw, Haslet, Samson , Park, White Settlement, Rhome, Boyd, Paradise, Bridgeport, Decatur	http://www.techsplanet.com/
Nextel	Nationwide	http://www.nextel.com/
People's Wireless	Wood, Rains counties	http://www.peoplescom.net/
T-Mobile	Nationwide	http://tmobile.com/

Table 3-6, continued.

Carrier	Coverage Areas	URL
TWIN Wireless, Inc	Lower Rio Grande Valley, Texas.	http://www.twin.net/
US Cellular	Nationwide	http://www.uscc.com/
Verizon Wireless	Nationwide	http://www.verizonwireless.com/
West Central Wireless	Texas	http://www.westcentral.com/
Western Wireless	Amarillo, West Texas, and South East New Mexico	http://www.wwamarillo.com/
XIT Cellular	Extreme North Western Texas	http://www.xit.net/

3.4. Wireless Communication System Vendors/Contractors

Representative wireless communication system vendors and contractors are listed in Appendix E.

Chapter 4. Strategies for Wireless Communication Configuration and Technology Selection

This chapter discusses the strategies for selecting wireless communication technology for ITS applications in a cost-effective and minimal-risk manner. Acquiring communication technology could be an ill-structured and complicated problem, primarily because communication technology is typically only a part of the IT system to enable traffic operation applications. Multiple feasible IT system configurations may exist, and the use of communication technology may vary widely. For example, in the application to send video data back to TMC, engineers could choose to utilize a configuration in which short-range wireless communication technology is used to send video data from cameras down to the roadside cabinet (so that no wire is needed between the camera and cabinet) and use wireline technology (ISDN, T1, T3, or fiber optics) to feed the video back to the center. Alternative configurations may allow the camera to send the video data directly back to TMC without involving any wireline technology. In response to such a wide range of possible network and system configurations, the best practice begins with thorough and careful system architecture and configuration design. After this process, several distinct configurations that involve wireline or wireless technologies at varying degrees may be derived. Further cost- and risk-analysis will then be applied to these candidate configurations in order to select the most cost-effective and minimal-risk configuration.

Due to the scope of this project, the discussion in this regard is limited to situations in which wireless technology is assumed to be involved in the configuration, regardless of the degree of involvement. Thus the configuration exclusively concerned with wireline technology will not be included in the discussion. The *lease* and *own* options that are extensively discussed in subsequent sections of this report stand for the consideration of whether to lease (from a service provider) or own (procure the equipment) the wireless portion of the system configuration. The methodology discussed in this report is significantly applicable to configurations that primarily employ wireless technology.

This chapter first discusses the budget and risk considerations associated with selecting wireless technologies, and then it explains the research approach—life-cycle cost and risk analysis. The guidelines for applying this method are illustrated through an example in Section 4.3.

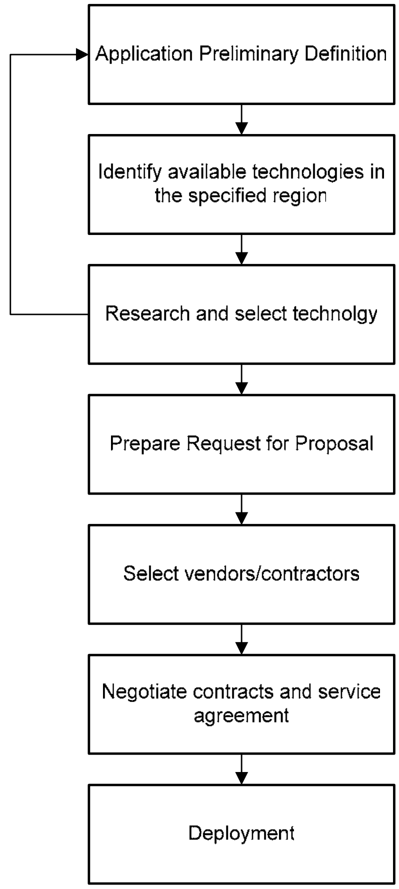

Figure 4-1. Wireless technology acquisition project process.

As shown in Figure 4–1, a wireless technology acquisition project generally consists of the following steps:

- Step 1: Define application and specify requirements.
- Step 2: Identify feasible technology alternatives.
- Step 3: Research and select technology.
- Step 4: Prepare request for proposal.
- Step 5: Select vendors/contractors (through letting and biding).
- Step 6: Negotiate contract and service agreement.
- Step 7: Deployment.

Common applications for traffic operation and ITS include communication between fixed-location stations (remote traffic detectors, video camera, or traffic signal controls, AVI beacon, etc.) and TMC, or communication between mobile units (i.e., mobile work zone management units or courtesy patrol vehicles) and TMC. The data rate requirement varies widely depending on the application. As shown in Tables 9–1 to 9–3, the data transmission rate (kbps) could range from hundreds to several thousands.

The process could also consist of iterations of its subprocesses. After research, if no suitable technology can be identified based on the specified requirements, a revisit of some of the requirements may be called for. Typical requirements that may need to be revisited are line-of-sight requirement and data transmission rate requirement. In many cases, these requirements can be loosened by, for example, reducing the number of frames per second for video applications. Therefore, iterations between Steps 1 and 3 are quite common in many cases.

4.1. Budget and Risk Consideration in Wireless Technology Acquisition

There are risks associated with any decision. Making wireless technology acquisition decisions comes with unique risks. These risks can be generally termed *reliability risk* and *obsolete risk*. *Reliability risk* exists because no technology is perfect. It is impossible to guarantee that any system will function as intended 100% of the time throughout its life cycle. There are numerous possible factors to cause failure or significantly degrade the performance of a wireless communication system, including irregular maintenance, component failure, natural causes (lightening) or man-made causes (sabotage or frequency saturation in the region). If an *own* decision is to be made, then the TxDOT will be exposed to all of the above types of *reliability risk.* Even though the system malfunction may be covered by the manufacturer's warranty or service agreement by the contractor, the down time is still inevitable, and its duration depends upon how soon the failed part is repaired. The degree of impact of such a risk could vary from one district to another, depending on the level of ITS technical staffing and degree of expertise in wireless technology. If a district has proficient in-house expertise, repairs could be immediately initiated with minimal cost. If a vendor/contractor needs to be called up, the repair is contingent upon the vendor's/contractor's responsiveness. Extra repair costs may be unavoidable.

If a *lease* decision is to be made, then TxDOT will be exposed to different types of *reliability risk*. The service provider could bring down the service for regular maintenance or upgrade. System malfunction can be caused by any of a number of unknown factors. In such an event, TxDOT will have very limited control over how soon the service can be resumed. It depends primarily on the service provider's responsiveness to the problem. Bringing the service back online will not incur any extra cost for TxDOT since it is the service provider's responsibility.

Based on interviews with TxDOT engineers conducted by the researchers (for summary, see 0), it is clear that these risks could be perceived very differently from district to district. A wireless technology-savvy district may be more willing to live with *own risk* than others, because engineers are capable of making judgments as to the course of action, and of predicting the time it will take to bring back online capability. The district may be more willing to pay a potentially higher cost to increase predictability. Other districts, which may not be as comfortable in handling the technology in-house, may consider the *lease* option better meets their needs, because it generally requires less in-house expertise.

Furthermore, when comparing the *lease* and *own* options, budget structure is another significant consideration for TxDOT engineers. The *own* option requires budgeting the expenditure in the current or upcoming fiscal year (from the long-term capital improvement budget or the yearly operating and maintenance [O&M] budget). Once the equipment (system) is acquired, the O&M and future upgrade costs (due to technology turnover) is allocated to future budgets. The lease option incurs less start-up capital investment, but will require significantly more O&M funds in future years. Deferring the expenditure to later years has theoretical advantages, because future dollar has less worth from the standpoint of current time. Furthermore, the funds saved in the current fiscal year can be invested in other traffic management actions, which may generate additional benefits (contribute to higher return of investment [ROI]). However, some TxDOT engineers express concerns about accruing higher O&M cost in future fiscal years, because it may impact future funding for traffic operation/management works. In several cases, getting the system in place using the funds in the current year is considered less risky than depending on future funds. Such concerns indicate that deferring the expenditure to the later year is not always preferable. As discussed earlier, the wireless technology funds saved in the current fiscal year, if used in other traffic operation tasks (such as purchasing traffic control devices for other purposes), may generate additional return on investment. However, unless such a collateral benefit is considered in the decision process, then deferring the expenditure is likely to be viewed in terms of future financial burden and uncertain impact on future traffic operations.

Another type of risk associated with wireless technology is o*bsolete risk*, which is realized when the technology becomes outdated and is no longer supported by manufacturers or service providers. As a result, the system or service based on such outdated technology becomes difficult and costly to maintain/upgrade, or support is entirely unavailable.

Such a risk exists because of two reasons. First, wireless technology has been advancing at an accelerated pace in the last decade. As shown in Table 4–2, wireless technologies have experienced several major milestones in every decade from the early 1900s. In the 1990s major technology advancements and milestones were announced in almost every year. A recent incident causing TxDOT district offices to scramble was the "sunsetting" of CDPD (Cellular Digital Packet Data) technology. CDPD was initially developed by the U.S. Cellular operators in the early 1990s. After one decade of deployment, it has become one of the most widely deployed cellular wireless data communication technologies in the United States. However, its available transmission data rate fell behind the increasing requirements of many audio/video oriented ITS applications. Furthermore, with the accelerated development of 2.5G or 3G cellular technology in late 1990s, more advanced data communication systems are ready to replace CDPD, and wireless carriers have decided to upgrade to newer technology and phase out CDPD. AT&T Wireless and Verizon Wireless, two of the major CDPD service providers, have recently announced that they are "sunsetting" CDPD wireless technology in June 2004 and December 2005, respectively. Districts like Dallas have had to modify their ongoing contract with Verizon for its traffic surveillance application in order to opt in Verizon's newly deployed technology (e.g., 1xRTT nationwide or 3G CDMA 1xEV-DO in San Diego and Washington, D.C., as of late 2003).

The second *obsolete risk* contributing factor stems from system design practice that tends to suggest existing and proven technology. Generally speaking, government agencies are about 2 years behind the curve. *Obsolete risk* arises with this principle. If the selected technology reaches the end of its life span during the life cycle of the application (say 7 to 10 years), district offices face the need to undertake a major upgrade of the system. The cost associated with this upgrade could be high. To avoid such a pitfall, thoroughly examining the future life span of alternative wireless technologies becomes crucial to the decision process. Undertaking this task is not difficult, but will require careful review of the latest technology reports/news, or consultation of other sources.

1896	Guglielmo Marconi develops the first wireless telegraph system
1927	First commercial radiotelephone service operated between Britain and the US
1946	First car-based mobile telephone set up in St. Louis, using 'push-to-talk' technology
1948	Claude Shannon publishes two benchmark papers on Information Theory, containing the basis for data compression (source encoding) and error detection and correction (channel encoding)
1950	TD-2, the first terrestrial microwave telecommunication system, installed to support 2400 telephone circuits
1950's	Late in the decade, several 'push-to-talk' mobile systems established in big cities for CB-radio, taxis, police, etc.
1950's	Late in the decade, the first paging access control equipment (PACE) paging systems established
1960's	Early in the decade, the Improved Mobile Telephone System (IMTS) developed with simultaneous transmit and receive, more channels and greater power
1962	The first communication satellite, Telstar, launched into orbit
1964	The International Telecommunications Satellite Consortium (INTELSAT) established, and in 1965 launches the Early Bird geostationary satellite
1968	Defense Advanced Research Projects Agency – US (DARPA) selected BBN to develop the Advanced Research Projects Agency Network (ARPANET), the father of the modern Internet
1970's	Packet switching emerges as an efficient means of data communications, with the X.25 standard emerging late in the decade
1977	The Advanced Mobile Phone System (AMPS), invented by Bell Labs, first installed in the US with geographic regions divided into 'cells' (i.e. cellular telephone)
1983	January 1, TCP/IP selected as the official protocol for the ARPANET, leading to rapid growth
1990	Motorola files FCC application for permission to launch 77 (revised down to 66) low earth orbit communication satellites, known as the Iridium System (element 77 is Iridium)
1992	One-millionth host connected to the Internet with the size now approximately doubling every year
1993	Internet Protocol version 4 (IPv4) established for reliable transmission over the Internet in conjunction with the Transport Control Protocol (TCP)
1994-5	FCC licenses the Personal Communication Services (PCS) spectrum (1.7 to 2.3 GHz) for $7.7 billion
1998	Ericsson, IBM, Intel, Nokia, and Toshiba announce they will join to develop Bluetooth for wireless data exchange between handheld computers or cellular phones and stationary computers
1990's	Late in the decade, Virtual Private Networks (VPNs) based on the Layer 2 Tunneling Protocol (L2TP) and IPSEC security techniques become available
2000	802.11 (b)-based networks are in popular demand
2000-01	Wired Equivalent Privacy (WEP) Security is broken. The search for greater security for 802.11 (x)-based networks increases

Figure 4-2. A brief timeline (1896-2001) in wireless technologies evaluation (Dubendorf, 2003).

4.2. Life-Cycle Cost and Risk Analysis

The life-cycle cost and risk analysis (LCCRA) proposed in this research aims to facilitate a sound but simple decision-making process. LCCRA is composed of a life-cycle cost analysis (LCCA) and a life-cycle risk analysis (LCRA). LCCA is an engineering economic analysis tool useful in comparing the relative merits of competing alternatives. LCRA is a risk assessment tool that allows TxDOT engineers to explicitly assess risks and costs associated with different technology options.

In the next section the LCCA will be introduced, followed by an explanation of LCRA. The procedure for applying the LCCRA to a particular wireless technology selection is illustrated using an example in the next section.

4.2.1. Life-Cycle Cost Analysis

LCCA calls for a consideration of all of the costs incurred during the service life of a transportation asset (the wireless technology to be acquired, in our case). These costs are represented in terms of present value (PV) in LCCA. As shown in Figure 4–3, the idea behind LCCA is that communication technology investment decision-makers should consider all of the costs accrued during the period over which the alternatives are being compared. Communication technology, commonly seen as a traffic operation asset, is required to provide service for many years. The ability of such an asset to provide service over time is predicted assuming its being maintained appropriately by TxDOT. Thus the investment decision should consider not only the initial activity that creates a public good, but also all future activities that will be required to keep that investment available for future traffic operations. Those future activities are part of the alternatives as much as the initial action is. Without periodic maintenance, the technology will not provide continued use to the TxDOT and to the public

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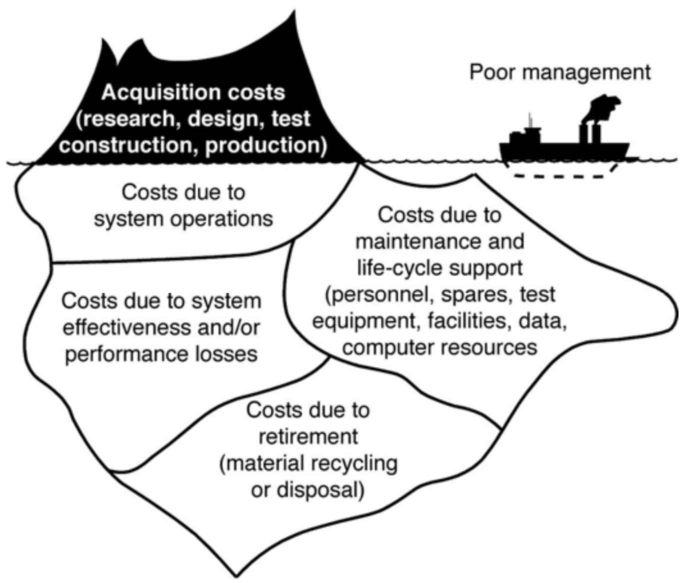

Figure 4-3. Total cost concept (Blanchard, 1998).

Wireless technology selection decisions generally require that several alternatives be considered. Many factors may contribute to a TxDOT engineer's final decision. Although initial deployment costs may dominate this decision, the initial agency cost is only part of the story. The technology alternative selected will commit TxDOT to future expenditures for maintenance over the life cycle of the technology product or service. Furthermore, the selected alternative will accrue costs to facility users through project activities that directly impact the traveling public. LCCA provides the means to include total cost to both agency and the user in the acquisition decision. Additionally, the structure and documentation of the LCCA process provide TxDOT with the ability to enhance the stewardship of the public's investment. Documentation is also a resource that TxDOT can use to educate newer employees and to maintain institutional knowledge.

Life-cycle cost analysis (LCCA) has been promoted by the Federal Highway Administration (FHWA) to be used in major transportation investment decision making for many years. As the inline table shows, FHWA has continued establishing guidelines in the last decade to assist federal and state agencies apply LCCA to major transportation investment decisions. In the area of making ITS technology investment decisions, however, there has been relatively limited guidance provided by FHWA or other national ITS organizations.

Figure 4–4 depicts the timeline of a typical communication system. After the system is initially deployed, engineers' satisfaction regarding this system steadily declines because of increasing transmission rate requirement (due to expanded and sophisticated applications) or the aging of system that requires more frequent maintenance. If an engineer decides to upgrade the system, the performance of the system is elevated along with his satisfaction. The performance satisfaction continues to decline following the upgrade for the same reasons. Thus, the second upgrade takes place after further aging of the system. Eventually, the system reaches the end of its life cycle and needs to be retired.

KEY LIFE-CYCLE COST ANALYSIS (LCCA) MILEPOSTS

1991—The Intermodal Surface Transportation Equity Act suggested that LCCA be considered in the design and engineering of bridges, tunnels, and pavements.

1995—The National Highway System (NHS) Designation Act mandated that States conduct LCCA on all high-cost projects (more than $25 million) constructed with Federal funding.

1996—The Federal Highway Administration (FHWA) produced Demonstration Project 115, "Life-Cycle Cost Analysis in Pavement Design," and by July 2002 had brought these techniques to more than 40 State transportation agency pavement design groups.

1998—The Transportation Equity Act for the 21st Century rescinded the LCCA mandate of the 1995 NHS Designation Act. States are no longer required to perform LCCA, but FHWA is directed to further develop the analysis methodology.

1998—FHWA published its pavement LCCA Interim Technical Bulletin, *Life-Cycle Cost Analysis in Pavement Design.*

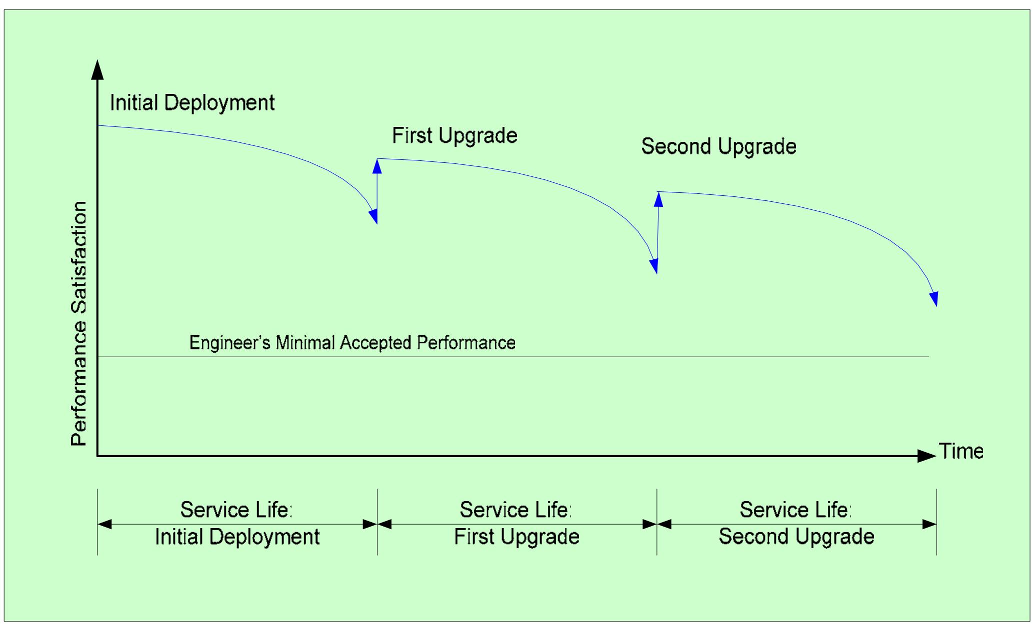

Figure 4-4. Example of lifetime of a wireless technology alternative.

The LCCA process consists of the following steps. The sequence of these steps is designed so that the analysis builds upon information gathered in prior steps.

- Step 1: Determine technology alternative.
- Step 2: Determine activity timing.
- Step 3: Estimate costs.
- Step 4: Compute life-cycle costs.
- Step 5: Analyze results.

STEP 1: Determine communication alternatives.
The LCCA process is called for when communication needs are identified for a particular traffic operation application. Available communication alternatives may encompass a wide spectrum of alternatives. Alternatives that could be considered include:

- Wireline communication alternative—lease
  Most of the ILEC (incumbent local exchange carrier, such as SBC or any other Bell company), or CLEC (competitive local exchange carrier, which were established after telecommunication deregulation in 1996) offer various types of wireline communication services, ranging from ISDN, DSL, T1, T3, etc. Users typically need to pay a monthly service fee for the service. The cost structure for this type of communication service includes purchase of communication devices (e.g., modems and cables) to be installed at the premise and monthly service charges. The monthly service charge may vary depending on the data rate. Some service bundles also include voice and data services. There is no remaining service life value at the end of the service period.

- Wireless communication alternative—lease
  Similar to the wireline communication alternative, the ILEC and CLEC could also provide wireless communication services. An increasing number of such carriers primarily focus on providing wireless services in cities of Texas. As shown in Tables 3–5 and 3–6, there are almost 50 nationwide, regional, or local wireless service providers in Texas. Most of the nationwide carriers offer both wireless voice and data services using varying technologies, such as PCS, GPRS, CDPD, EDGE, 1xRTT, 1xEV-DO, etc. Many regional or local providers offer voice services only; several of them offer wireless broadband services via MMDS, LMDS, or above cellular technologies. The cost structure for such types of communication service includes purchases of communication devices (e.g., modems and wires) to be installed at the premise and monthly service charges. The monthly service charge varies depending on data rate and number of connections required. Some service bundles also include voice and data services. There is no remaining service life value at the end of the service period.

- Wireless communication alternative—own
  Owning wireless communication equipment or system is considered when a small-scale deployment is needed and line-of-sight is not an issue. The transmission range may or may not be an issue. If extended transmission range is required, a transceiver and an amplifier may be installed to extend the transmission range for spread spectrum radio. For microwave, the transmission range naturally goes up to several tens of miles. The cost structure for this alternative includes purchasing equipment and labor for the initial deployment, regular O&M cost, and future upgrade costs. There are certain remaining service life values at the end of the service period.

STEP 2: Determine activity timing.
Activity timing is the duration over which the life-cycle cost is calculated, the time period over which the current decision may impact. It can be longer or shorter than the technology life cycle; however, it is recommended that the activity timing includes at least one or two major system upgrades or even entire system retirement. It is suggested that the activity timing to be defined between 5 – 10 years because of the following considerations:

- Moore's Law[30]—the fundamental governing rules of modern digital computation power—indicates 18 months as the life cycle for new generations of micro-chip.
- Prevalent operating system such as Microsoft Windows ® underwent five major upgrades from 1992 to 2002 (Windows 3.X to Windows XP), averaging 2 years a version. On the average, major compatibility issues arise every four years (from 16-bit version to 32-bit version, and the 64-bit version has just been announced in late 2003).
- The evaluation of cellular wireless technologies suggests that the 2G and 2.5G cellular networks have a good possibility of facing "sunsetting" in the foreseeable future, because it is predicted that 80% of the U.S. market will be covered with 3G network by 2005. Several years later, when the 3G becomes mature and cost effective, the 2G and 2.5G may become today's CDPD, facing the discontinued support from major national operators. It is speculated that the 2G and 2.5G services are still provided in regional areas. Therefore, the "sunsetting" of these technologies is speculated to be between 2010 and 2015, but could widely vary geographically. On other hand, other wireless technologies such as spread spectrum radio, microwave, radio paging, land mobile, and satellites, etc. are more likely to extend longer life span because of less fluctuation in this area. (See Table 4–1.)

Table 4-1. Expected future life span of various cellular wireless technologies.

	Commercialization (Year)	Phase out (possible Year)
Cellular (2 – 3G)		
1st Generation Wireless		
AMPS	1980s	2005
CDPD	1993	2005
2nd Generation Wireless		
GSM	1990s	2010–2015?
PCS (IS-136)	1990s	2010–2015?
PCS (IS-95)	1990s	2010–2015?
2.5 Generation Wireless		
GPRS	1990s	2010–2015?
1xRTT	1990s	2010–2015?
EDGE	1990s	2010–2015?
3rd Generation Wireless		
UTMS (WCDMA)	2003	?
1xEV-DO (CDMA 2000)	2003	?

[30] The observation made in 1965 by Gordon Moore, co-founder of Intel, that the number of transistors per square inch on integrated circuits had doubled every year since the integrated circuit was invented. Moore predicted that this trend would continue for the foreseeable future. In subsequent years, the pace slowed down a bit, but data density has doubled approximately every 18 months, and this is the current definition of Moore's Law, which Moore himself has blessed. Most experts, including Moore himself, expect Moore's Law to hold for at least another two decades.

	Commercialization (Year)	Phase out (possible Year)
Others (Spread Spectrum, microwave)		
Spread Spectrum Radio	1970s	?
Microwave	1970s	?
Radio paging	1970s	?
Land Mobile	1970s	?
Satellite	1970s	?

STEP 3: Estimate costs.
The cost structure for lease and own alternatives could include the following items. Depending on the service provision and equipment characteristics, not all the cost items need to be considered.

- Lease
  - Labor cost—initial installation of device at site
  - Equipment cost—initial installation of device at site
  - Initial training cost—engineer's time to learn how to operate the equipment/service
  - Service cost—monthly service charge for the service
  - Operator manpower—engineer's time required to operate the equipment
  - Upgrade cost—cost to upgrade to new services

- Own
  - Labor cost—initial installation of device at site
  - Equipment cost—initial installation of device at site
  - Initial training cost—engineer's time to learn how to operate the equipment
  - Operation and maintenance cost—cost to operate and maintain (due to system component failure) the equipment
  - Operator manpower—engineer's time required to operate the equipment
  - Upgrade cost—cost to upgrade and software and/or hardware
  - Salvage value—the remaining value of the equipment at the end of analysis period

Estimating these costs could be done using three different methods:

Known factors or rates are inputs to the LCCA which have a known accuracy. For example, if the unit cost and quantity are known, then the initial installation equipment costs can be calculated. If staff cost and equipment utilization are known, then the operator manpower cost can be calculated (i.e. staff cost (per hour) * hours used per month).

Cost estimating relationships are derived from historical or empirical data. For example, from experience, one may be able to estimate the service contract cost from prior similar service contracts. The cost estimating relationship can be complex and needs to be exercised with caution.

Expert Opinion: Although open to debate, it is often the only method available when real data is unobtainable. When expert opinion is used in LCCA, it should include the assumptions and rationale that support the opinion.

The expenditure activities throughout the activity timing can be expressed in an expenditure diagram. Figure 4–5 illustrates the activities, timing, and associated costs in an expenditure diagram.

Constructing this diagram is an important step in estimating the life-cycle costs. Depending on the activities initiated at different times, necessary cost items should be estimated.

For wireless technology the timing for some activities may be difficult to predict precisely. For example, how many future system software/hardware upgrades are needed and at what time they will occur is unknown at the time of decision. Whether the technology becomes obsolete during the analysis period is also unknown. The uncertainty of the timing of these activities will be explicitly modeled in the life-cycle risk analysis that will be explained in section 4.2.2. In LCCRA the expenditure diagram is associated with individual scenarios in which the timing of various activities is assumed.

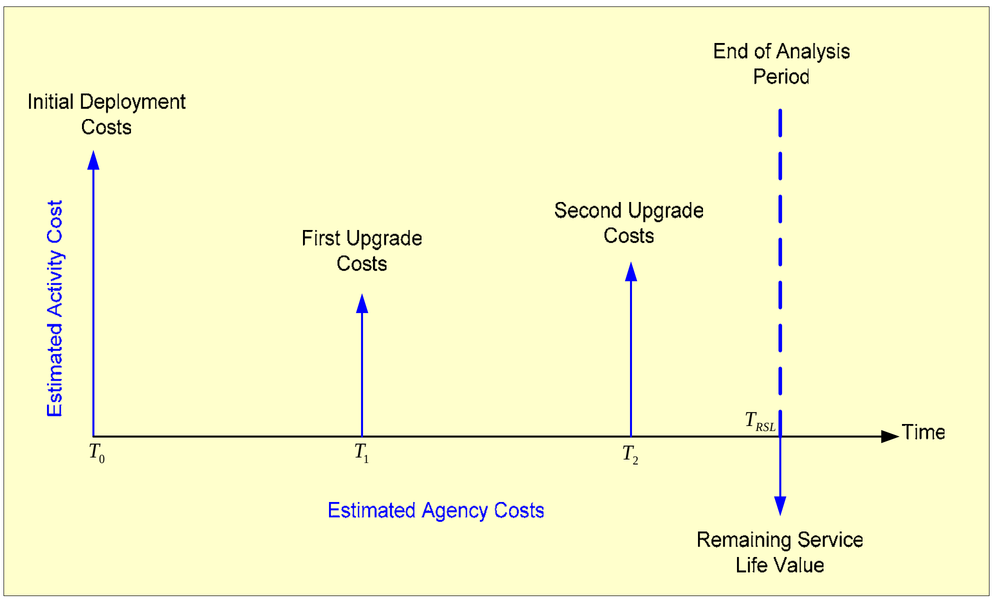

Figure 4-5. Expenditure diagram with activity, costs, and timing shown.

STEP 4: Compute life-cycle costs.

There are two approaches to preparing an LCCA: deterministic and probabilistic. The methods differ in the way they address the variability and uncertainty associated with LCCA input data, such as activity costs, activity timing, and discount rate. There have been extensive discussions about the limitations and advantages of the deterministic LCCA approach in the literature. The probabilistic approach is generally regarded as a more robust method. However, this approach requires significantly more input data and takes more time to complete. Thus it may be less applicable in wireless technology selection because of the budget size and time constraints for this task. Thus, the deterministic approach has been selected for this study. The uncertainty and variability aspects of the problem will be addressed in Section 4.2.2.

The deterministic approach assigns each LCCA input variable (cost, timing, etc.) a fixed, discrete value. The engineer determines the value most likely to occur for each input variable. This determination can be based on historical evidence, professional judgment, consultation with other engineers, or study of various sources including the Internet. Deterministic LCC computation is straightforward and can be conducted manually using a calculator or automatically with a computer spreadsheet program (i.e., MS Excel). In this research, the calculation of LCC has been implemented in a web-based knowledge management system (WBKMS) and in a MS Excel worksheet, which will be discussed later in this chapter.

The results of deterministic analysis can be enhanced through the use of a technique called sensitivity analysis. This procedure involves changing a single input variable of interest, such as the discount rate or activity costs, over the range of its possible values while holding others constant, and estimating a series of present values (PVs). Each PV result reflects the effect of input change. In this way input variables may be ranked according to their impacts on the bottom-line conclusions. This information could be important to engineers who want to understand the variability associated with alternative options. It also allows the engineer to identify those input factors or economic conditions that warrant special attention.

The method for converting the future value to current value is called discounting. The reason for discounting is that cost of benefits occurring at different points in time—past, present, and future—can not be compared without considering the *opportunity value of time*. The *opportunity value of time* as it applies to current versus future funds can be understood in terms of the economic return that could be earned on funds in their next best alternative use (e.g., the fund could be earning interest or could be invested in other traffic operation strategies to introduce other benefits) or the compensation that must be paid to induce an engineer to defer an additional amount of current year consumption for one year. In other words, reducing the value of future cost makes deferring the expenditure relatively attractive. A lower discounting rate discounts less of future value, or discourages deferring the expenditure to future years. A discounting rate of 7% is suggested by the Federal Government. [31] According to the discussions in preceding sections, TxDOT engineers may not necessarily prefer deferring the expenditure to future years. In this case, he/she may choose to take a lower discounting rate. Furthermore, applying the discounting also implies that inflation for all costs is approximately equal, and thus inflation is usually considered embedded in the discounting and is not calculated separately.

The formula for discounting can be expressed as:

$$\text{present value} = \text{future value} \times \frac{1}{(1+r)^n}$$

Where

r = discounting rate, 7%, based on OMB Circular No. A-94[32]; however, a lower rate (2–5%) is used in this research

n = number of years in the future when the cost will be incurred

This step involves analyzing and interpreting the LCCA results. With the deterministic LCCs computed, the PVs of the differential costs may be compared across competing alternatives. In this research, the LCCs are treated as inputs of the life-cycle risk analysis (LCRA) and will be not used as the final outcome for comparison. It is generally recommended that both agency and use costs be included in the LCC. In wireless technology selection application, it is extremely difficult to estimate the user costs resulting from various activities during the analysis duration; thus only agency costs are considered.

[31] OMB Circular No. A-94

[32] http://www.whitehouse.gov/omb/circulars/a094/a094.html

4.2.2. Life-Cycle Risk Analysis

As discussed in the preceding section, emerging wireless technologies always come with several competing standards that may not be compatible with each other. While the technology becomes standardized, mature, and proven (which is generally preferred by government agency), a newer generation of the similar technology or even entirely different technology may emerge. Cellular wireless technologies, particularly the 2G or 2.5G technologies (GPRS, EDGE, 1xRTT, etc.), have become mature but may be phased out in a foreseeable future. Their future life span depends on the path of technology advancement, competition and market adaptation of 3G technology. Other wireless technologies (e.g., spread spectrum radio, microwave, etc.) may exhibit longer life spans than interim cellular technologies. The short and unpredictable life cycle of wireless technology, defined as *obsolete risk*, makes technology selection decision risky.

Engineers may also have different perceptions and tolerances toward risk, depending on personal preferences, applications, and budget constraints. A more risky but less costly alternative may be preferred because of budget constraints. A less risky but costly option may be chosen because it provides a higher data rate that may soon to be needed. Recognizing the *obsolete risk* and varying perceptions of risk, this research develops life-cycle risk analysis (LCRA) risk assessment guidelines in conjunction with LCCA to consider the risk-based life-cycle costs. The LCRA is a *decision tree* based approach, in which the entire decision problem is represented through a set of possible decision scenarios. Each scenario is a combination of actions and subsequent outcomes of actions. A typical decision tree is rooted in a decision node (represented as a square-shaped node as in Figure 4–6), which represents the selection of several feasible alternatives. The alternatives represented by the branches from a decision node must be such that the decision makers can choose only one alternative. For example, the engineer can choose only Configuration 1 or 2, but not both. In some cases, a combination of strategies is possible. In this case, the three alternatives should be Configuration 1, 2, or a hybrid. In this case, each of the three separate alternatives would be modeled explicitly, yielding three branches from the decision node.

Each chance node (represented as the circle-shaped node in Figure 4–6) must have branches that correspond to a set of mutually exclusive and collectively exhaustive outcomes. Mutually exclusive means that only one of the outcomes can happen. Being collectively exhaustive means that no other possibilities exist; one of the specified outcomes has to occur. Putting these two specifications together means that when the uncertainty is resolved, one and only one of the outcomes occurs. Furthermore, a decision tree represents all of the possible paths that a decision maker might follow through time, including all possible decision alternatives and outcomes of chance event.

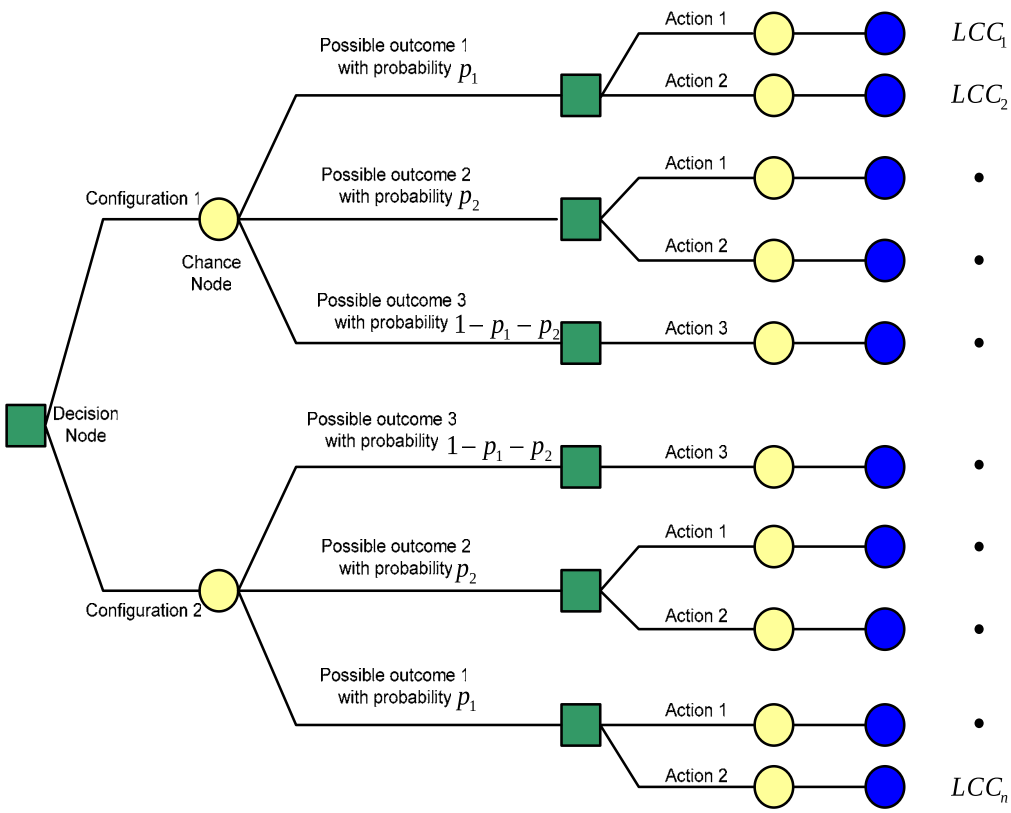

Figure 4-6. Decision tree framework.

The right-most nodes represent the final outcomes of different scenarios beginning with the root node and following different paths. These outcomes are the life-cycle costs (LCCs) for each scenario. The LCCs of a particular scenario, as described in the preceding section, include the LCCs of various activities in the life cycle of the selected technology. Since some of the activities (i.e., number of major upgrades, chance of technology becoming obsolete at different times, etc.) are uncertain, this decision tree method allows engineers to analyze the LCCs under various realizations of probabilistic occurrence of these major events that incur varying LCCs.

Finally, it is useful to think of the nodes as occurring in a time sequence. Beginning on the left side of the tree, the first thing to happen is typically a decision, followed by another decision, or chance events occurring in chronological order.

4.3. Life-Cycle Cost and Risk Analysis Guideline

The procedure for the LCCRA is briefly described as follows. It is best understood through an example, which will be given in this section. The methods for LCCRA have been implemented in a Web-based knowledge management system to cope with general decision situations: (http://atrl.utep.edu/telecom/DSM/dsm_home.php?type=4). The Microsoft Excel spreadsheet for the example is also included in the CD that accompanies this report.

Leasing or owning wireless technology/service is often called for in applications such as having remote traffic detectors or video cameras communicate with TMC. In urban areas where existing

TxDOT-owned ITS infrastructure is typically in place (i.e., fiber networks), the decision is relatively easy since utilizing existing infrastructure is the best choice. If the application is located in a rural area where no ITS infrastructure exists, and budget is a concern, then leasing or owning the technology deserves careful consideration.

It is suggested that, given such a decision context, engineers follow the steps depicted in Figure 4–7.

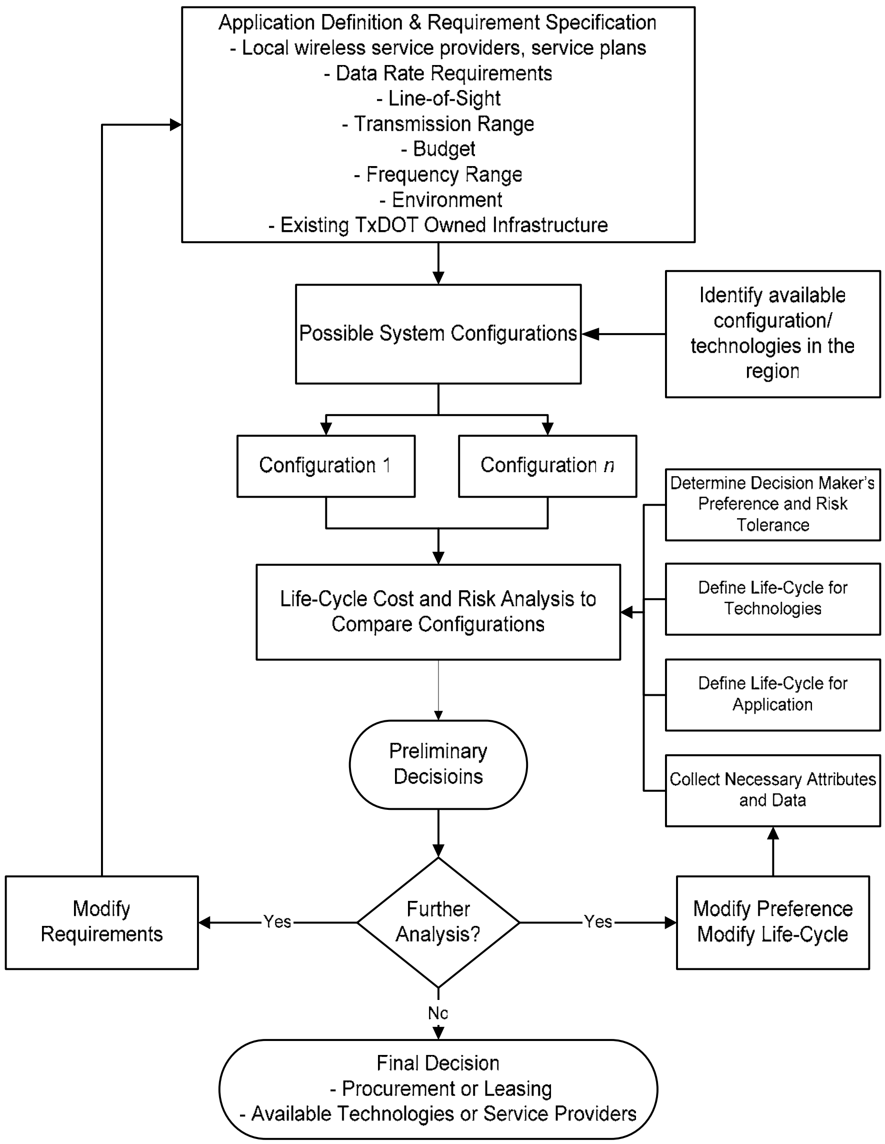

Figure 4-7. Decision framework for lease or own decision.

In this framework, the decision process is organized into several steps. These steps are explained using a hypothetical example, as follows:

A TxDOT district needs to monitor traffic on a rural freeway corridor using several video imaging vehicle detection systems, which include cameras and vehicle detection processors. The distances from the cameras to the TMC range from 2,000 ft. to 10 miles. The video data will need to be sent back to the TMC located at the district office.

Stage 1: Application definition and requirement specification.
Important information that should be identified in this step includes:

- Local Cellular Wireless or Wireline Service Providers, Service Plans
  SBC is the ILEC for the wireless service; there are a few national and regional wireless voice and data service carriers. The available cellular wireless service available in the region is CDPD and GRPS. The CDPD and GPRS service costs $40-80/month/unit.

- Data Rate Requirements
  In this example, the data need to be transmitted are the vehicle detection data and the video feeds. The transmission rate requirement is flexible because the video resolution (number of frames per second) can be adjusted based on the available transmission rate.

- Line-of-Sight
  Line-of-sight is available for most of the sites.

- Transmission Range
  The transmission range varies from 2,000 ft. to 10 miles.

- Life-Cycle Budget
  Uncertain; most likely less than $400k.

- Frequency Range
  Unlicensed (*own* option) or unrestricted (*lease* option).

- Terrain
  Flat terrain, slightly hilly.

- Existing TxDOT -Owned ITS Infrastructure
  No TxDOT-owned ITS infrastructure (such as fiber optics) exists.

Stage 2: Identify feasible technology alternatives.
Prior to identifying feasible technology alternatives, system configurations need to be designed. Let us assume there are three possible candidate configurations. As shown in Figures 4–8 to 4–10, in Configuration 1, the data are transmitted directly to the center wirelessly.[33] In Configuration 2, the data are transmitted from cameras to the cabinet, and then wireline is used to send data to the TMC. In Configuration 3, the data are sent to the center using cellular technology. In other words, the data are sent to the wireless carrier's base station and relayed to the TMC. Wireless technology is employed in different ways in these configurations. In the first configuration, line-of-sight is required, and the transmissions range from thousands of feet to miles. The available data transmission rate depends on the wireless technology employed. Prevalent technologies available for this configuration are spread spectrum radio and microwave. These technologies are typically acquired through procurement, or they could be included as a part of the camera systems.

[33] For remote sites that are 10 miles away, signals can be relayed by transceivers and amplifiers.

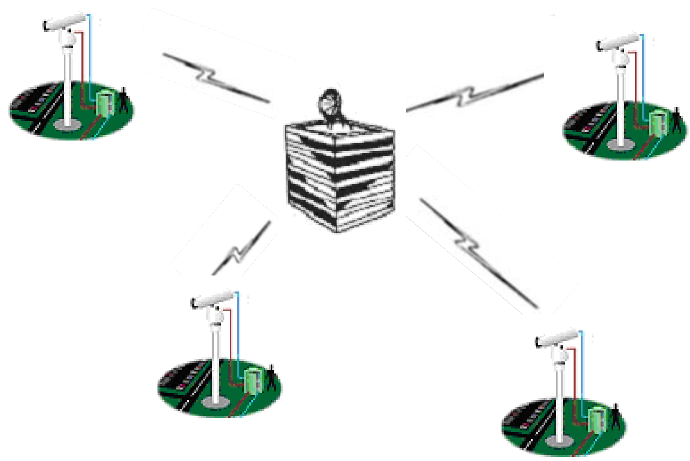

Figure 4-8. Example of system configuration (1).

In the second configuration, only short-range communication is needed (hundreds of feet). The available data transmission depends on a minimum of wireless and wireline technology. Prevalent technology for this configuration is 802.11x-based technology. The wireline service could be regular phone line, ISDN, T1, T3, frame relay, or OC-X. The wireless technology used is typically acquired through procurement, or it could be included as a part of the wireless camera systems.

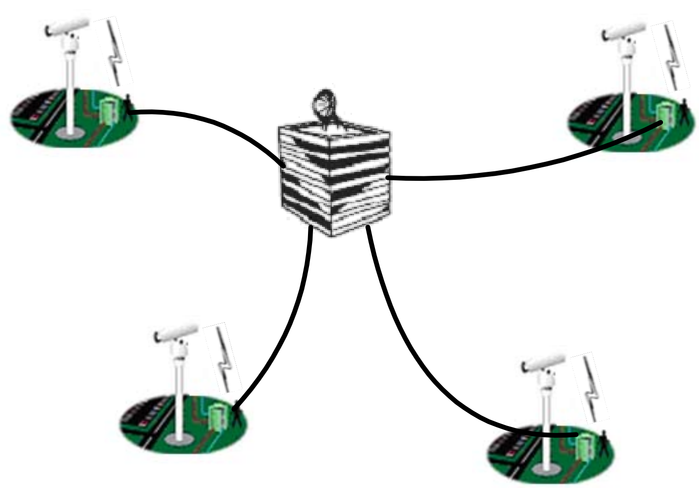

Figure 4-9. Example of system configuration (2).

In the third configuration, the cameras transmit data back to the center through a wireless service provider's base station. The available data transmission rate depends on the technology that the service provider uses, and it also may depend on the service plan. The technologies in this area are currently experiencing rapid migration. The recently phased out CDPD technology belongs to this area. Prevalent techniques include GPRS (GSM-based), EDGE (GSM-based), and 1xRTT (CDMA-based). These are 2.5G technologies. The 3G technologies, including 1xEV-DO (CDMA2000 based), and UMTS (WCDMA) will rapidly deployed in the near future. It is anticipated that the dominating 3G technology in the United States is CDMA2000-based technology. The only way to acquire this technology is through subscribing to the service; the modems may need to be purchased.

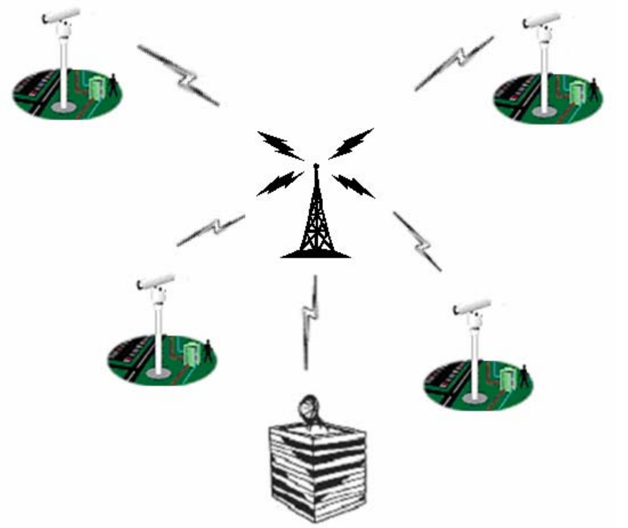

Figure 4-10. Example of system configuration (3).

Feasible technologies or services that come with the *lease* option can be identified through calling national or regional wireless service providers. Different service providers use different technologies that may require purchasing different type of communication devices installed at premises.

Feasible technologies or services that come with the *own* option can be identified in several ways, including: (1) Log onto the Web-based knowledge management system developed by the researchers for this project (http://atrl.utep.edu/telecom)—this site is expected to operate continuously from 2003 to 2006—to (a) search the latest technology news, tutorials, glossary, etc.; (b) post project information onto the Project Center to solicit information for interested parties; (c) to post related questions on to the Discussion Forum (these questions will automatically be forwarded to a technical support panel, which is composed of other TxDOT engineers, vendors/contractors, and other professional engineers. (2) Consult with other TxDOT engineers or other engineers/consultants via various channels. (3) Survey the Internet for related information. It is obvious that for any new projects, it is effective and efficient to start from the WBKMS, because all the features provided on this website are primarily designed to support TxDOT engineers' wireless technology acquisition needs. Detail eddescriptions of this WBKMS are provided in Chapter 6.

Stage 3: Research and select configuration

As discussed earlier, wireless technology is employed differently in individual configurations. Simply analyzing the wireless portion does not provide the whole picture. In the following example, the LCCRA is discussed based on the configurations, with many assumptions made for wireline technologies. The use of the LCCRA for this example is described in following actions:

Step 1: Define the analysis period.

As discussed earlier, choose an analysis duration between 5 and 10 years.

Step 2: Construct decision tree diagram.

The decision tree diagram captures major uncertain events (which will incur significant costs) throughout the life cycle of a particular configuration. The tree starts from the root decision node—select one from the three candidate configurations. Three branches emanating from the decision node connect to three individual chance nodes. The chance nodes represent major uncertain events during the life cycle of each configuration. In Configuration 1, the major uncertain event is "major upgrade needed during life cycle" with probability p_{1-1}. In Configuration 2, same uncertain event is identified with probability p_{2-1}. In Configuration 3, same uncertain event is identified with probability p_{3-2}. An additional "technology becomes obsolete in life cycle" event is also identified with probability p_{3-1}, because cellular technology is expected to experience major upgrades and changes in the foreseeable future. Each uncertain event's associated probability needs to be estimated. Such information can be approximated based on experience, or on discussions with vendors, manufacturers, contractors, or telecom operators. For spread spectrum radio or microwave technologies, major upgrades may not be needed in 5–10 years. For 802.11x technology major upgrades may be likely because it is evolving rapidly. For cellular technology, not only may major upgrades be needed, but technology may become obsolete, depending on the technology employed. The possibility for 2.5G technology to become obsolete in 10–15 years is not trivial. The 3G technology is not in danger of obsolescence, but the technology is not proven, and coverage is limited.

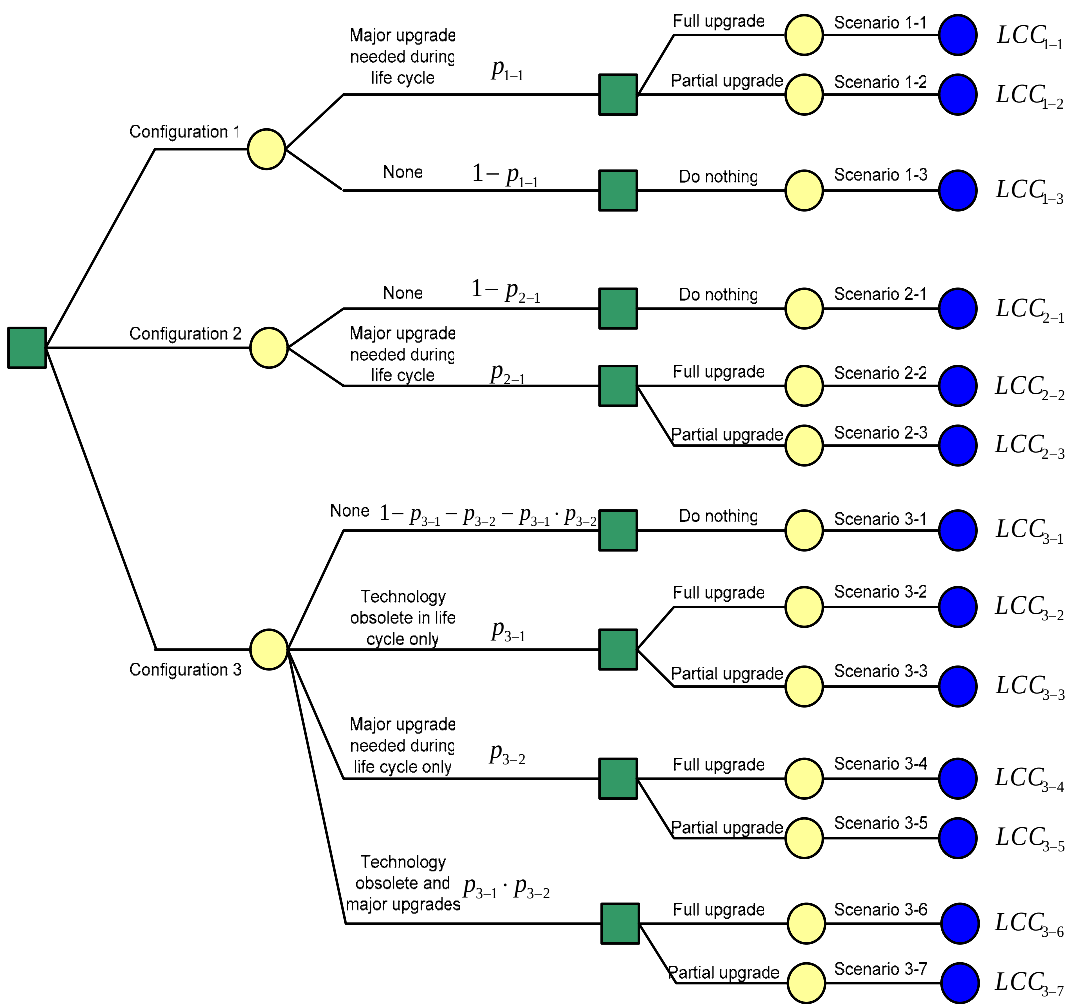

Figure 4-11. Decision diagram for the application example.

Following each possible event, a decision node is further defined. For each decision node, possible action to mitigate the uncertainty is defined. In the event that major upgrade is needed during the life cycle, there are two possible actions: full upgrade or partial upgrade are defined. Once the action is chosen, the outcome node denotes the final life-cycle costs (LCCs) for this particular scenarario. A scenario is a unique path from the root decision node to the final outcome node. In this example, a total of 13 scenarios are identified.

The LCCs consists of deterministic costs that were discussed in section 4.2.1 and the probabilistic events specified in the decision tree. As an example, a scenario of choosing Configuration 1, then needing a major upgrade during the life cycle, followed by the decision to undertake the full upgrade (scenario 1) will accrue LCCs that include initial deployment, O&M, and the cost for upgrading the system. If partial upgrade is chosen, then the LCCs in this scenario (scenario 2) exclude the present value of the upgrade cost, but the initial deployment and O&M costs remain the same as those in scenario 1.

Step 3: Calculate the LCCs for each scenario.

LCCs can be calculated by first constructing an expenditure diagram. The expenditure diagram in Figure 4–12 defines the expenditure activities that occur in each year over the analysis period. The Year 1 expenditure includes the initial deployment costs and O&M. The system is assumed to be fully upgraded at Year 3, requiring certain upgrade costs. At the end of the analysis period, the system is assumed to have a certain remaining salvage value. The actual LCCs calculation for scenario 1-1 is listed in Table 4–2. All the worksheets for all the scenarios are listed in Chapter 10. The electronic version of the worksheets (MS Excel) is also included in the CD that accompanies this report. The major upgrade event is assumed to occur at Year 3. This assumption can later be changed by changing the occurrence year. Having the upgrade event occur at a different year results in different present values of the costs incurred by the event, thus affecting the total LCCs. This process is called sensitivity analysis. The sensitivity analysis can easily be done by using the worksheet included in the CD that accompanies this report.

It should be noted that the discounting rate is set to be zero for Year 1. Throughout the life cycle, it is set within a range of 0.2–0.5. Generally, the discounting rate decreases over time.

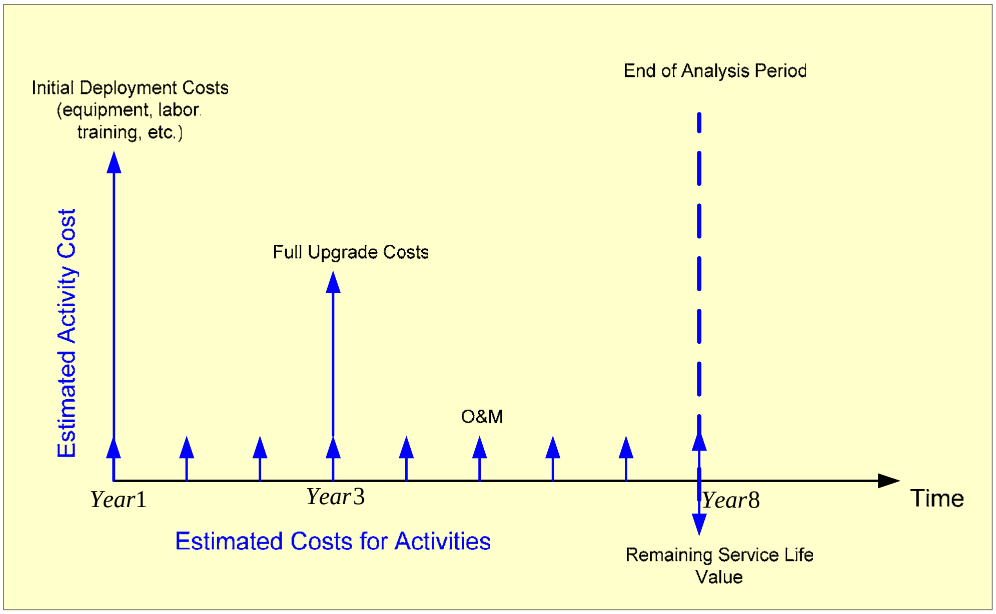

Figure 4-12. Expenditure diagram for scenario 1-1.

Table 4-2. Worksheet for calculating life-cycle cost for scenario 1-1.

Year (n)	Expenditure Item	Unit cost ($1000)	Unit	Subtotal (k) ($1000)	Discounting Rate (r%)	Present Value of Expenditure ($100) = $k \cdot \left[1 \big/ \left(1 + \frac{r}{100}\right)^n \right]$
1	Equipment (Camera, spread spectrum radio or Microwave)	12.50	20	250.00	0.00	250.00
1	Labor	10.00	1	10.00	0.00	10.00
1	O&M	0.50	1	0.50	0.00	0.50
1	Training (engineer time)	0.05	100	5.00	0.00	5.00
2	O&M	0.50	1	0.50	2.00	0.48
3	O&M	0.50	1	0.50	2.00	0.47
3	Full Upgrade	30.00	1	30.00	3.20	27.29
4	O&M	1.00	1	1.00	2.00	0.92
5	O&M	1.00	1	1.00	2.00	0.91
6	O&M	1.00	1	1.00	2.00	0.89
7	O&M	2.00	1	2.00	2.00	1.74
8	O&M	2.00	1	2.00	2.00	1.71
8	Salvage Value	-20.00	1	-20.00	2.00	-17.07
LCCs	**$282.84**					

Step 4: Select the alternative with minimal expected LCCs.

This step is done by moving from the outcome node backward to the root decision node. The calculation is discussed as follows:

1. List all the LCCs at each outcome node.

At the decision node that is "upstream" of the outcome node, write down the lower of the LCCs that emanate from this decision node. As an example, for the decision node that leads to two scenarios 1-1 and 1-2, the LCCs at the decision node are the lower LCCs of scenarios 1-1 and 1-2, which is the lower of [282.8, 277.2]. Doing so indicates that the best decision at the decision node is to conduct a partial upgrade because of lower LCCs.

2. Repeat the procedure for all the decision nodes.

Next, move one level higher. At each chance node above the decision nodes, calculate the weighted average LCCs using the following formula:

$$LCC_i = \sum p_k \cdot \min\{LCC \mid k\}$$

Where LCC_i is the average LCCs for Chance Node *i*,

p_k is the probability of event *k*,

$\min\{LCC \mid k\}$ is the minimal LCC given that event *k* occurs, which is the LCC calculated at 2.

3. Once calculation of all the LCC_i has been completed, the most cost-effective alternative based on the average LCCs is the alternative with the minimal LCC_i.

Calculate the variation of LCC_i by checking the largest and smallest LCCs associated with different events. For example, LCC variation for Configuration 1 is [265.6, 277.2]. That for Configuration 2 is [279.8, 287.6], and that for Configuration 3 is [298.3, 332.5].

Step 5: Reach preliminary conclusions by checking average and variation of LCCs.
From Figure 4–13 it is clear that Configuration 1 is the best choice with the minimal average LCCs at $264K. Configuration 2 requires $280.6K, while Configuration 3 requires the most at LCCs $302.4K. Comparing the range of LCC variation, Configuration 1 is $11.6K ($277.1 minus $265.6), while Configuration 2 has $7.8 [$287.6 minus $279.8]. Configuration 3 has the highest variation at $34.2K. These LCCs variation measures provide engineers with an idea of at what range the actual LCCs may be realized. Further checking confirms that the lowest possible LCCs for Configuration 2 ($279.8) is still higher than the highest LCC for Configuration 1 ($277.2), which suggests that Configuration 1 is not only the most cost-effective alternative but also the minimal-risk alternative.

Table 4-3. Decision tree analysis final results.

Decision Tree Worksheet		
CONFIGURATION	**PROB**	**LLCS OF BEST ACTION**
Configuration 1		
Major upgrade needed during life cycle	0.40	277.17
None	0.60	255.55
Average LLCs ($1000)	**264.20**	
Configuration 2		
Major upgrade needed during life cycle	0.10	287.64
None	0.90	279.81
Average LLCs ($1000)	**280.60**	
Configuration 3		
None	0.68	298.26
Technology obsolete	0.10	332.07
Major upgrade needed during life cycle	0.20	298.85
Technology obsolete and major upgrade	0.02	332.53
Average LLCs ($1000)	**302.44**	

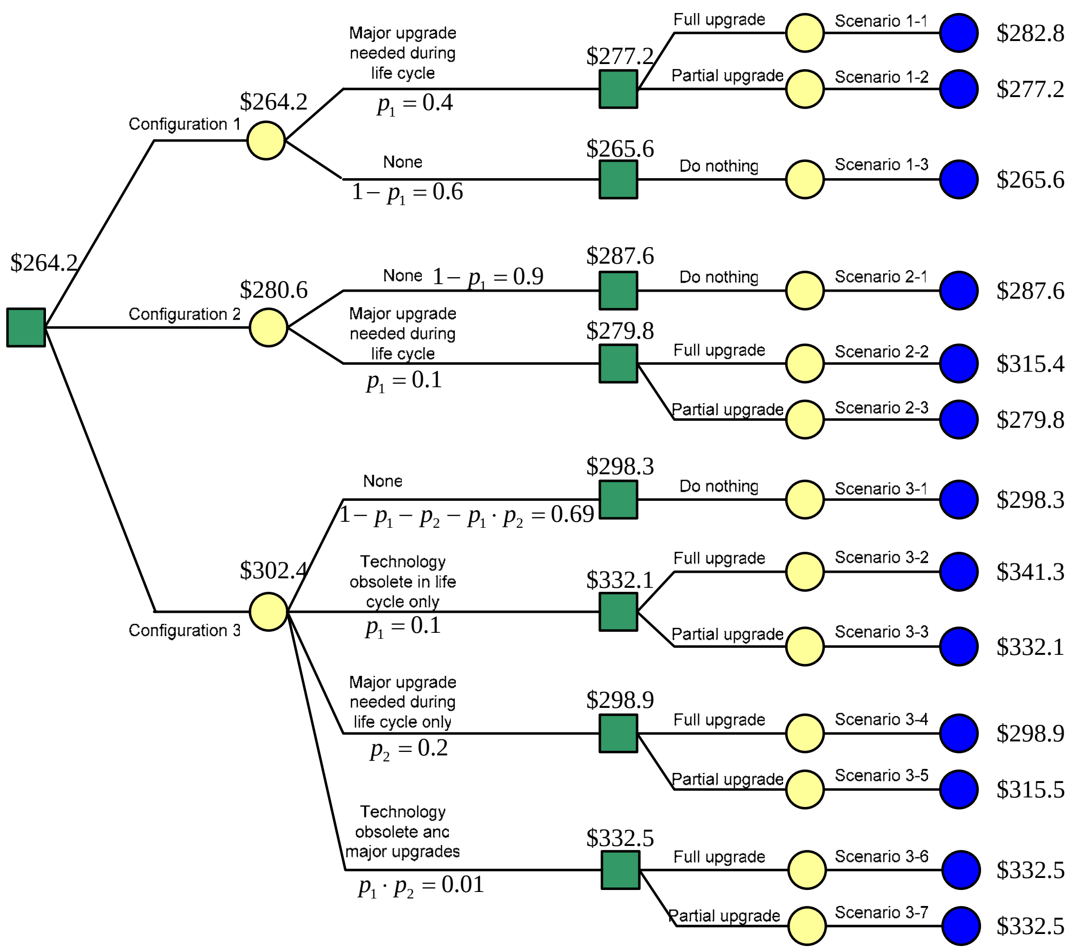

Figure 4-13. Life-cycle cost and risk analysis results for the example.

Stage 3: This step concludes the optimal network configuration (including technology) for the intended application.

The outcome of this step can further be used in the subsequent steps. However, the rest of the stages, including preparing the request for the proposal, selecting vendor/contractor, negotiating contract and service agreement, and conducting deployment are out of the scope of this research, and hence are not discussed. However, useful related information can be found in Eskelin (2001).

Chapter 5. Wireless Technology Acquisition Knowledge Management System

The creation of a Web-based knowledge management system (WBKMS) was motivated by interviews with TxDOT engineers. In these interviews, engineers expressed concerns about having to make their ITS wireless technology acquisition decisions based on very limited information. This situation was partly attributed to decision time constraints and partly to the lack of a mechanism to facilitate the formation of institutional knowledge and experience accessible to all TxDOT engineers. To remedy this situation, the researchers employed the concept and framework of knowledge management (KM), which has recently been increasingly emphasized in the public sector, and created a Web-based knowledge management system (WBKMS) that is specifically designed for assisting TxDOT engineers in coping with various aspects of decisions in ITS wireless technology acquisition.

This chapter discusses the concept of WBKMS and the development of a WBKMS for TxDOT engineers to assist in their decision process.

5.1. Knowledge Management Concept

Unfortunately, there is no universal definition of KM, just as there is no agreement as to what constitutes knowledge in the first place. Any attempt to define knowledge is complex, controversial, and capable of being interpreted in many different ways. Therefore, it is best to think of KM in the broadest context. KM could be viewed as the process through which organizations generate value and improve overall performance by identifying, developing, managing, and sharing their intellectual and knowledge-based assets. These intangible assets consist of human capital (employees' competence), structural capital (the internal structure of the organization), and customer capital (relationships with customers, suppliers, partners, or other external bodies.)

These assets can also be classified into two categories: explicit or tacit. As a general rule of thumb, explicit knowledge consists of anything that can be documented, archived, and codified, often with the help of information technology (IT). Much harder to grasp is the concept of tacit knowledge, or the know-how that is contained in people's heads. In other words, most of the challenges in KM are how to recognize, generate, share, and manage tacit knowledge.

Burk (1999) characterizes the notion of a "cycle of knowledge," in which four major knowledge processes take place repeatedly in a circular manner. Once one individual has formed certain knowledge through research, lesson, or production performance evaluation, he/she documents such knowledge via means of publications, conferences, etc. Such knowledge needs further organization so that it is easily shared and reused by other employees in the same organization and for those who are either new to the position or at a different position but in need of similar knowledge.

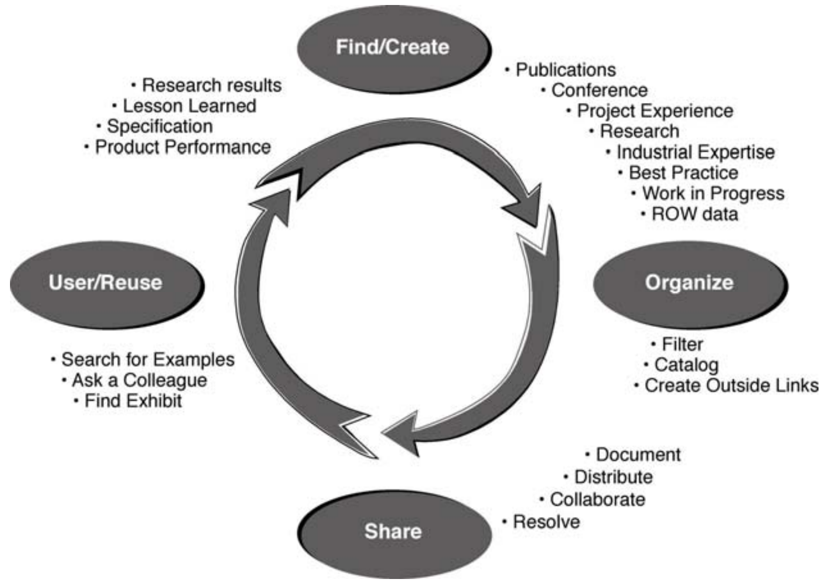

Figure 5-1. Cycle of knowledge (Burk, 1999).

Some benefits of KM contribute directly to the increase of profitability or bottom-line savings, while others are more difficult to quantify. From the perspective of improving the technology acquisition process for ITS application, an effective KM should help TxDOT to fulfill its mission by doing one or more of the following:

1. *Foster innovation by encouraging the free flow of ideas among engineers.*

Streamline operations and reduce costs by eliminating redundant or unnecessary processes. Experience in one district can be quickly shared and learned by others, to reduce the likelihood of repeating mistakes.

Identify the best practice for different decision contexts in order to improve overall transportation system performance.

2. *Minimize risks associated with technology acquisition decisions.*

Information Technology (IT) typically enables KM, but does not dictate KM. Commonly adopted disciplines in KM deployment include the areas shown in Table 5-1. Organizations typically implement a selected number of focused disciplines based on needs and the priority of achieving organizational mission.

Most commonly employed KM strategies as recently surveyed by Barquin and Clarke (2001) in federal government agencies indicate several prominent emphases that are being realized. These strategic themes include:

Using KM to produce a better information or knowledge product. This theme recognizes information as the core attribute of the product created by an agency and describes KM as the core process used to create it.

Using KM to improve operational efficiency by reducing structural cost. The key to strategic linkage in this case is demonstrating clear bottom-line benefits through the use of KM techniques.

Using KM to proactively deal with forecasted changes in the organization such as turnover and retirements, and using knowledge capturing activities as a way to bring new employees up to speed more rapidly. An additional goal could be capturing the knowledge of subject matter experts as they rotate through assignments.

Using KM to improve consistency in the way information is produced or processed and generally improving the ways in which teams work together. While these themes are more difficult to link to the organization's strategic mission, they still represent important activities in the organization.

Employing multiple KM disciplines for multiple organizational purposes. These multidimensional projects are noteworthy for their ambitious scopes and attempts to integrate social and technical design elements into a holistic approach.

Table 5-1. Commonly adopted KM disciplines.

KM Disciplines
Portals
Document Management
Community of Practice
Collaboration
Organizational Change
E-Learning
Content Management
Data Warehouse/Data Mining
Storytelling
Customer Relationship Management

The Federal Highway Administration (FHWA) is one of the federal transportation agencies that rigorously pursue excellence in adopting KM to fulfill their organizational missions. Burk (1999) discusses the strategies that the FHWA employs to facilitate knowledge sharing. These strategies include heighten awareness, initial projects, evaluate effectiveness, expand and replicate, develop expertise and champions. The FHWA also forms an internal community to share specialized knowledge and information, and to capture historical and valid knowledge from senior staff. Some of the discussions are organized by theme, such as safety and long-term strategic planning. Safety of the rumble strip (http://safety.fhwa.dot.gov/programs/rumble.htm) is a prototype of how members of an electronic community can share information, resolve technical issues, and publish results. The portals of the knowledge communities are heavily used by all researchers and staff at the FHWA (http://knowledge.fhwa.dot.gov/cops/FHWAKnowExt.nsf/intro).

Under the KM discipline definition, TxDOT has its portal website that provides documents and content management. The knowledge formation needed to facilitate the wireless technology acquisition decision process currently cannot be found on the website. As such, this project aims to design and implement an experimental KM system especially for this purpose. The reason it is viewed as an experimental system is that it attempts a ground-up approach in which ITS engineers participate in the knowledge formation. Minimal involvement of the top management of the organization makes it distinctly different from other proven paradigms in the literature. The advantage of such a grass-roots activity is that it agilely responds to the needs of engineers without having to wait for leadership from the top. The challenges are the potential lack of motivation to contribute and the absence of rewards for best practice.

5.2. Knowledge Management System Structure and Features

The knowledge management system developed from this research is designed to facilitate knowledge building and information/experience exchanges among TxDOT engineers in acquiring wireless communication technologies. Wireless communication technologies have currently been widely applied in ITS-related traffic operations in TxDOT jurisdictions. Although there are many districts with high levels of expertise and experience in dealing with the acquisition of wireless technologies for ITS applications, many of the smaller districts encounter difficulties when facing similar technology acquisition decision situations. Developments in wireless technology protocols, standards, or products are evolving rapidly. Unless one keeps track of the technology evolution constantly, one will often be in the dark when coming across a new jargon. The WBKMS is implemented as a Web-based clearinghouse, which entails the following objectives:

- To compile basic technical information regarding wireless communication technologies and technology acquisition project management in a single repository, in order to serve TxDOT engineers' various needs.
- To provide a platform to facilitate information sharing and communications among TxDOT engineers, vendors, and other wireless technology professionals.
- To provide basic decision support analysis for decisions such as procurement vs. leasing, or varying product configurations.

This Web-based clearinghouse is for members only, and registering on this site is free of charge. All the information that members provide is kept strictly confidential; none of the information is shared with anyone else. The reason for asking users to register is to ensure that all communications and information going on this Web site is of relevance to Web site users, and to continue proving the service of this clearinghouse. Once an engineer, vendor, contractor, or other professional registers, the Web site provides the member with personalized information—answers to posted information, responses to projects, etc. If a member volunteers to be a technical support panel (TSP) member, he/she will receive a weekly newsletter about the updates of activities on this Web site.

The main features of this WBKMS are introduced in next few sections.

Dynamically Updated Home Page

The main page of the WBKMS keeps dynamic contents; namely, it updates with latest information posted by members including the administrator, TxDOT engineers, vendors, contracts, and other professionals (Figure 5–2).

Figure 5-2. Main page of knowledge management system for wireless technology acquisition.

Personalized Homepage for Registered Members

The Web site requires a personal login to access features. Once logged in, each member will immediately see a personal main page, which lists the latest activities related to this member, discussion topics or projects posted (Figure 5–3).

Figure 5-3. Personalized homepage for registered members ***showing personalized information.***

Discussion Forums

This is an interactive message board that allows all members to interact with others by posting and replying to questions. This discussion forum has several unique features.

First, it sends out a relay alarm that notifies the person who posts a question whenever someone else has replied to the question. This way one does not need to constantly return to the Web site to check whether one's questions have been answered.

Second, the forum sends weekly newsletters to notify the technical support panel (TSP) about newly posted but unanswered questions in the forum. TSP members can easily return to the forum by clicking on the links in the newsletter. It is believed that TSP members are willing to help and can be even more helpful if we provide some reminders to their desktop on a regular basis Figure 5–4.

Figure 5-4. Main page of discussion forum.

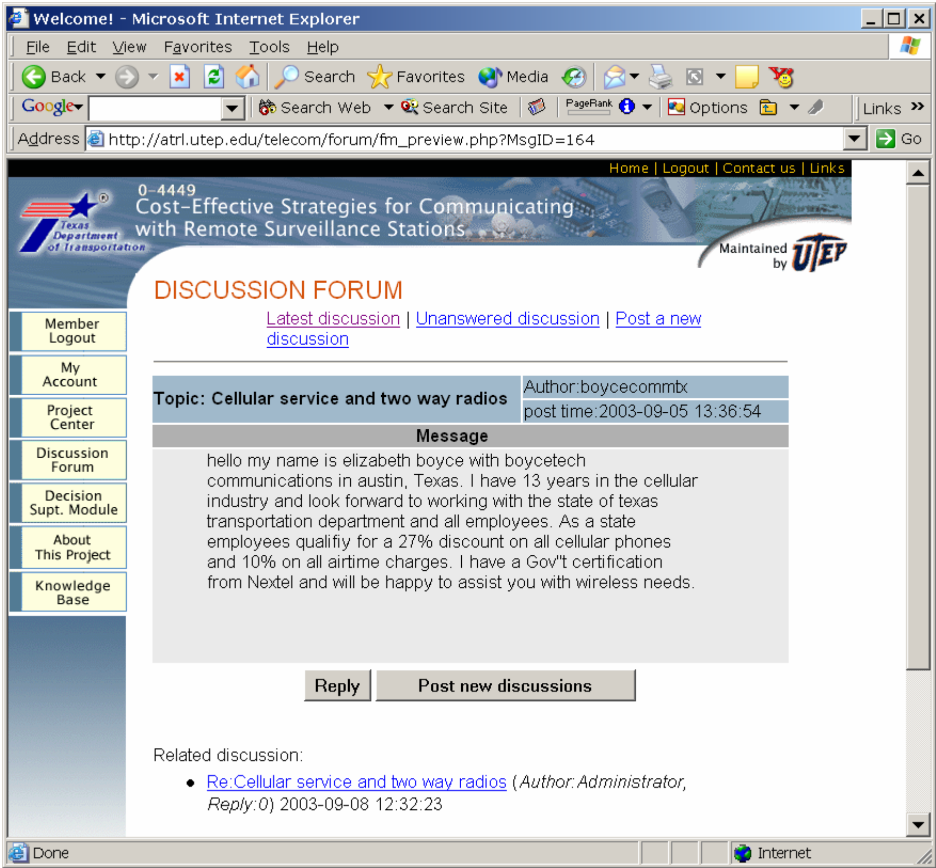

Figure 5-5. Threaded discussion lists and topics.

Project Center

In this section, TxDOT engineers can post their past and active wireless applications projects. This section provides a means to allow those who are interested in this project to request or send information to TxDOT engineers. One special feature of this section is that the TxDOT engineer's contact information is not revealed to others. In the meantime, others can choose to express their interest in this project and supply their contact information to TxDOT engineers. Such information will then be provided to the TxDOT engineer, and then the engineer can choose to initiate contact with interested parties. Project center management interface is also provided for TxDOT engineers so that they can easily create or delete project information (Figure 5–6).

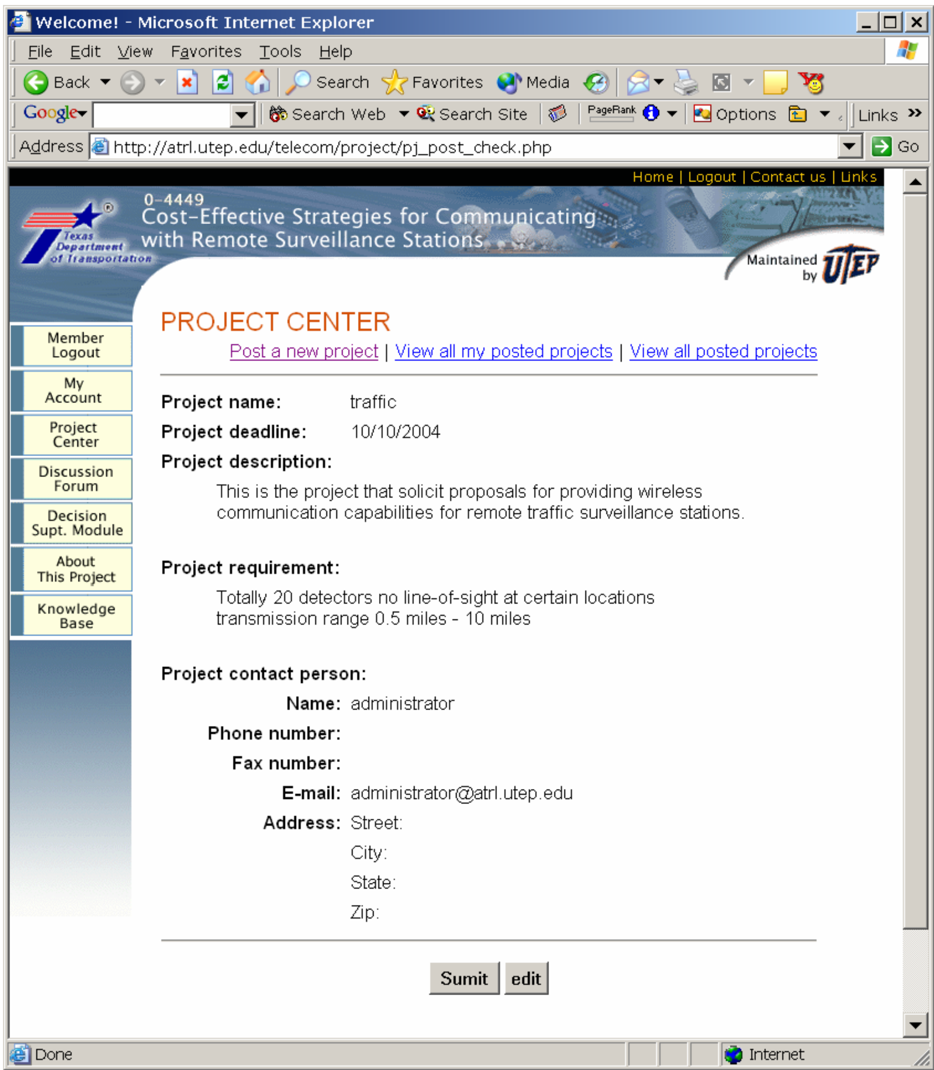

Figure 5-6. Example of project information, posted by TxDOT Engineer in Project Center. Decision Support Module (input/view – TxDOT engineers only).

The decision support model (DSM) is designed to help TxDOT engineers make informed decisions regarding the selection of cost-effective wireless communication alternatives. The DSM is structured to provide decision support for three types of decision contexts:

1. Looking for general technical information.

2. Having an application, not sure whether to procure or lease the appropriate technology.

3. Having already made a decision whether to procure or lease.

Different information compilation and accessing mechanisms are provided for each decision context. TxDOT engineers are welcome to access each module regardless of the decision situation at hand (Figures 5–7 and 5–9).

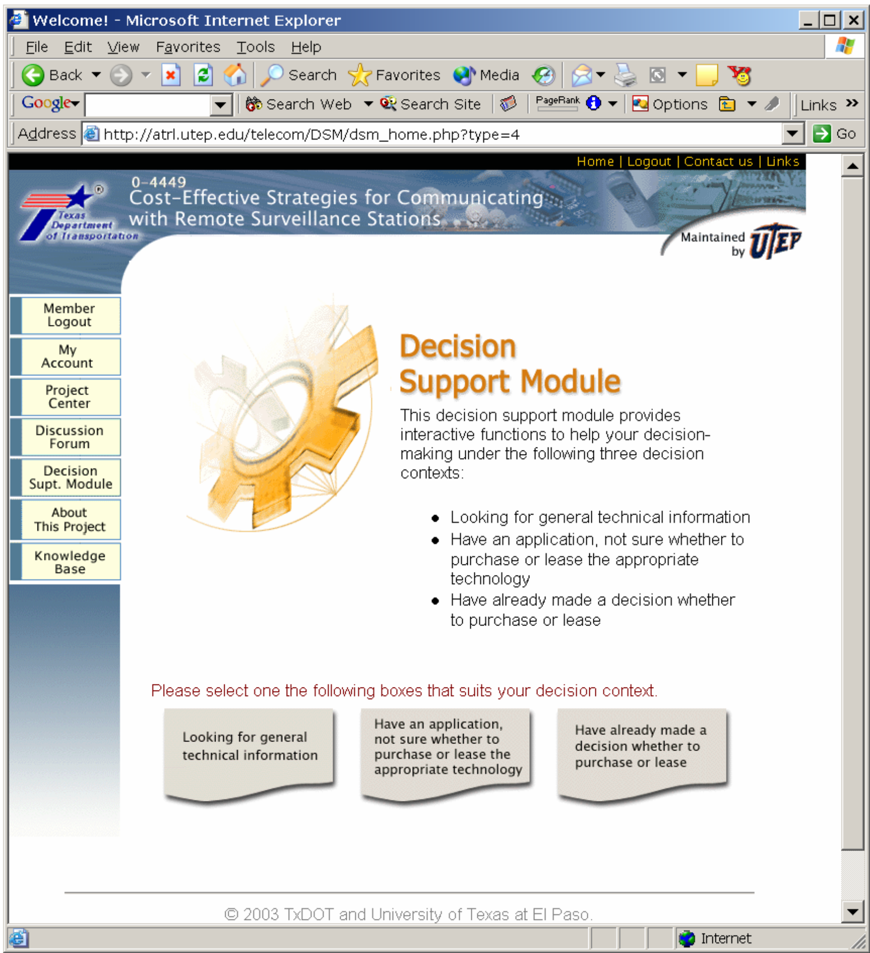

Figure 5-7. Main page of decision support module.

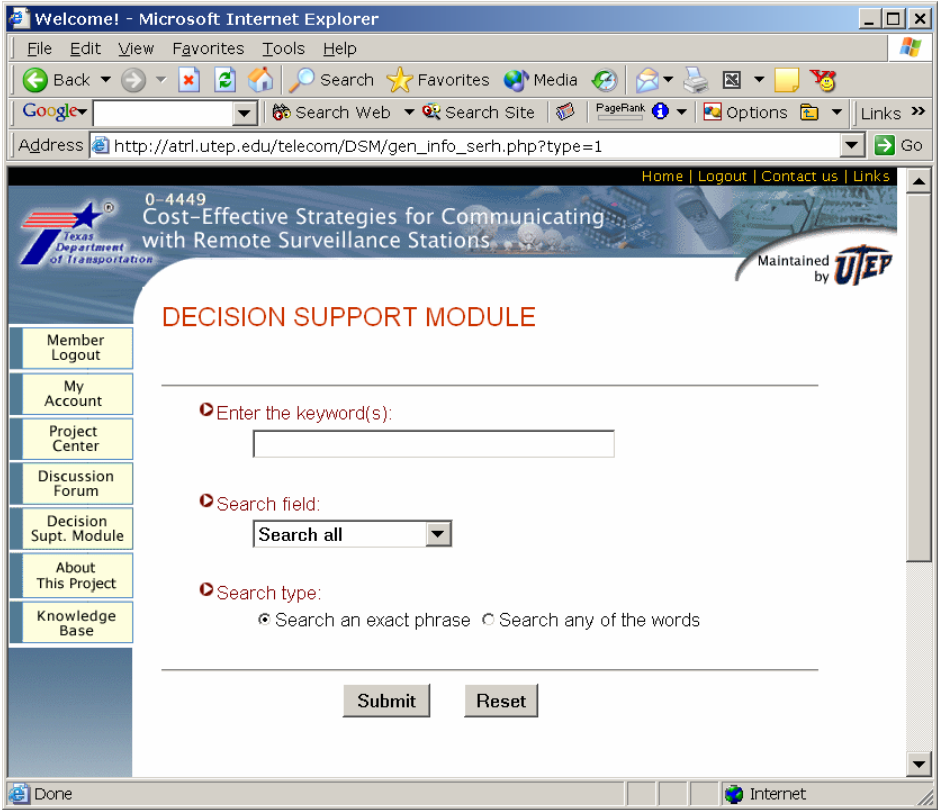

Figure 5-8. Decision support module – looking for general technical information.

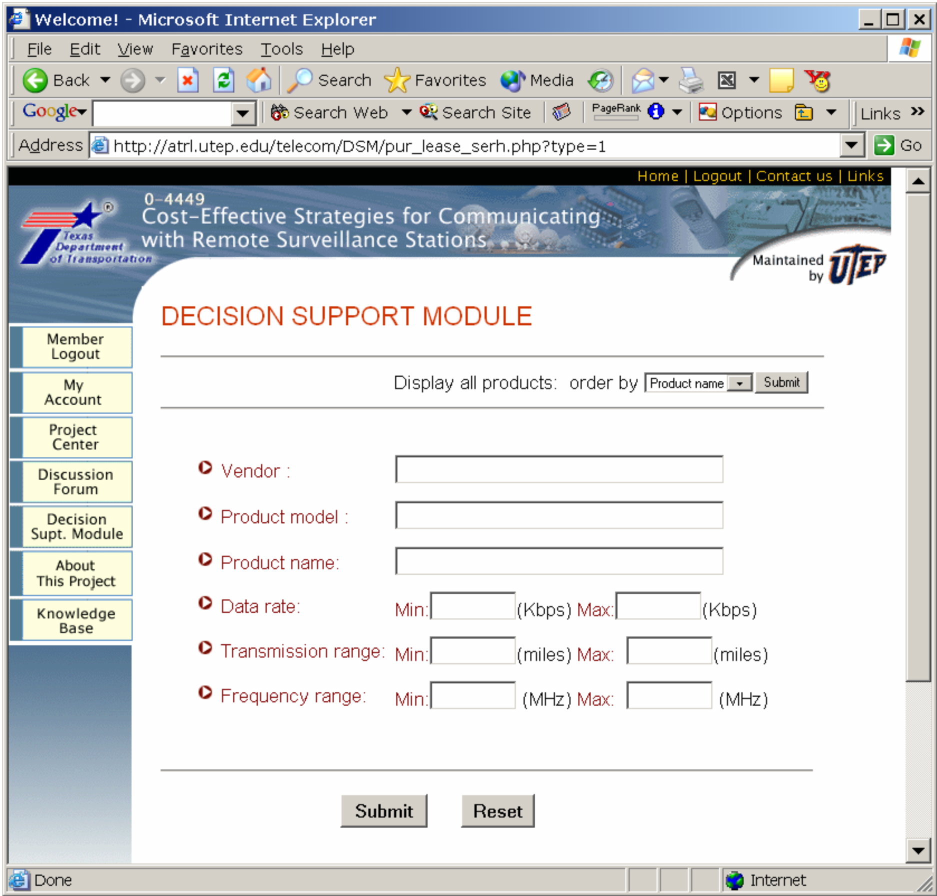

Figure 5-9. Decision support module – have made a lease *or* own *decision.*

Knowledge Base

This is the information repository to which all members can contribute in order to enrich its content scopes and depths. The information compiled in this knowledge base is principally categorized into three sections: Wireless Technology, Technology Project Management, and TxDOT Experience. The Wireless Technology section contains all the technical information pertaining to wireless technology, and the Technology Project Management section contains information relating to the full process of managing a wireless technology acquisition project, including planning, research, negotiation, procurement, operations, and retirement. TxDOT Experience contains the summaries of interviews with TxDOT engineers that researchers conducted throughout the project duration. While the research team strives to enrich the contents, members are also encouraged to contribute their knowledge and experience. Web-based interfaces are provided to each member to input relevant information. After all, learning from each other is the best way to build up the knowledge base in this area (Figures 5–10 and 5–13).

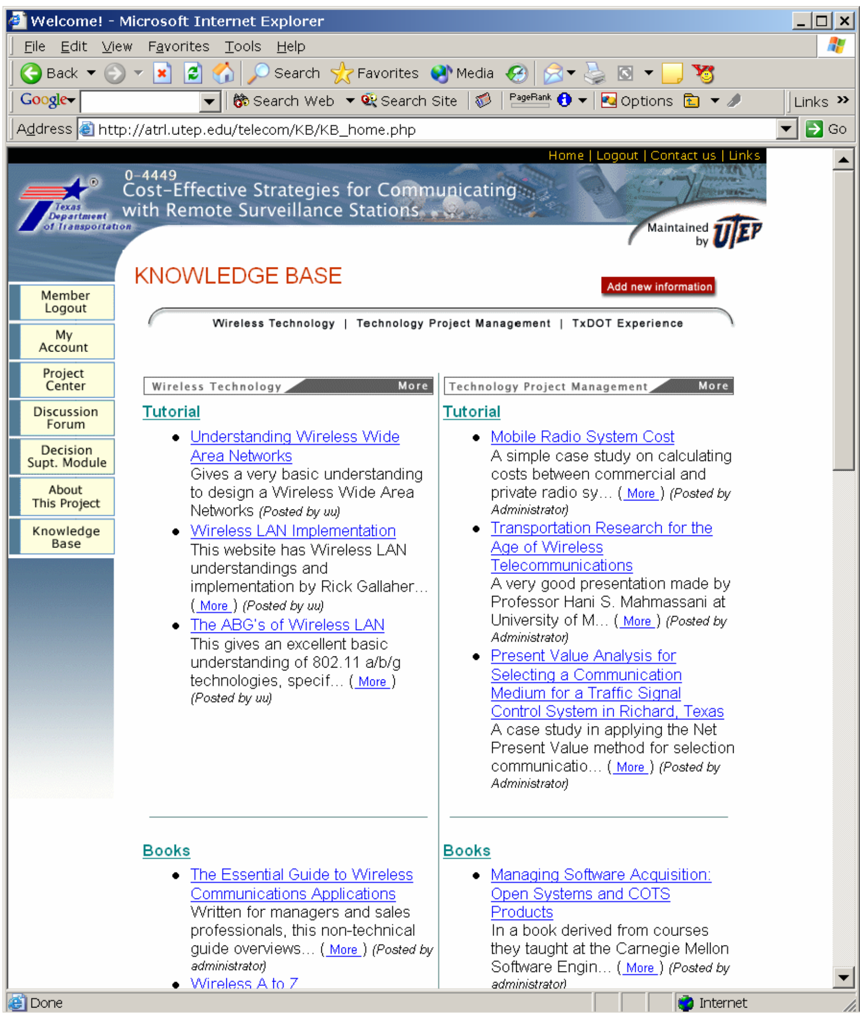

Figure 5-10. Main page of knowledge base.

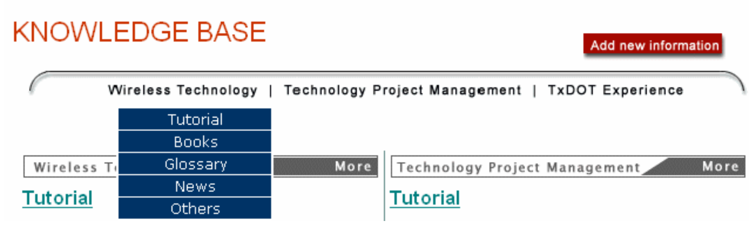

Figure 5-11. Subsections of wireless technology *knowledge base.*

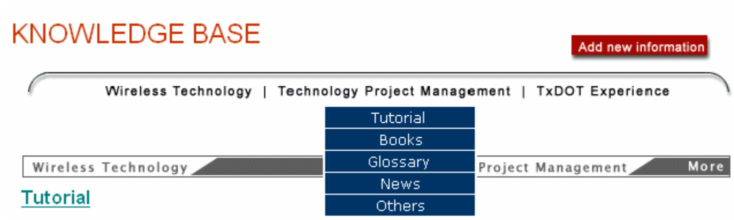

Figure 5-12. Subsections of wireless technology management *knowledge base.*

Figure 5-13. Subsections of TxDOT experience *knowledge base.*

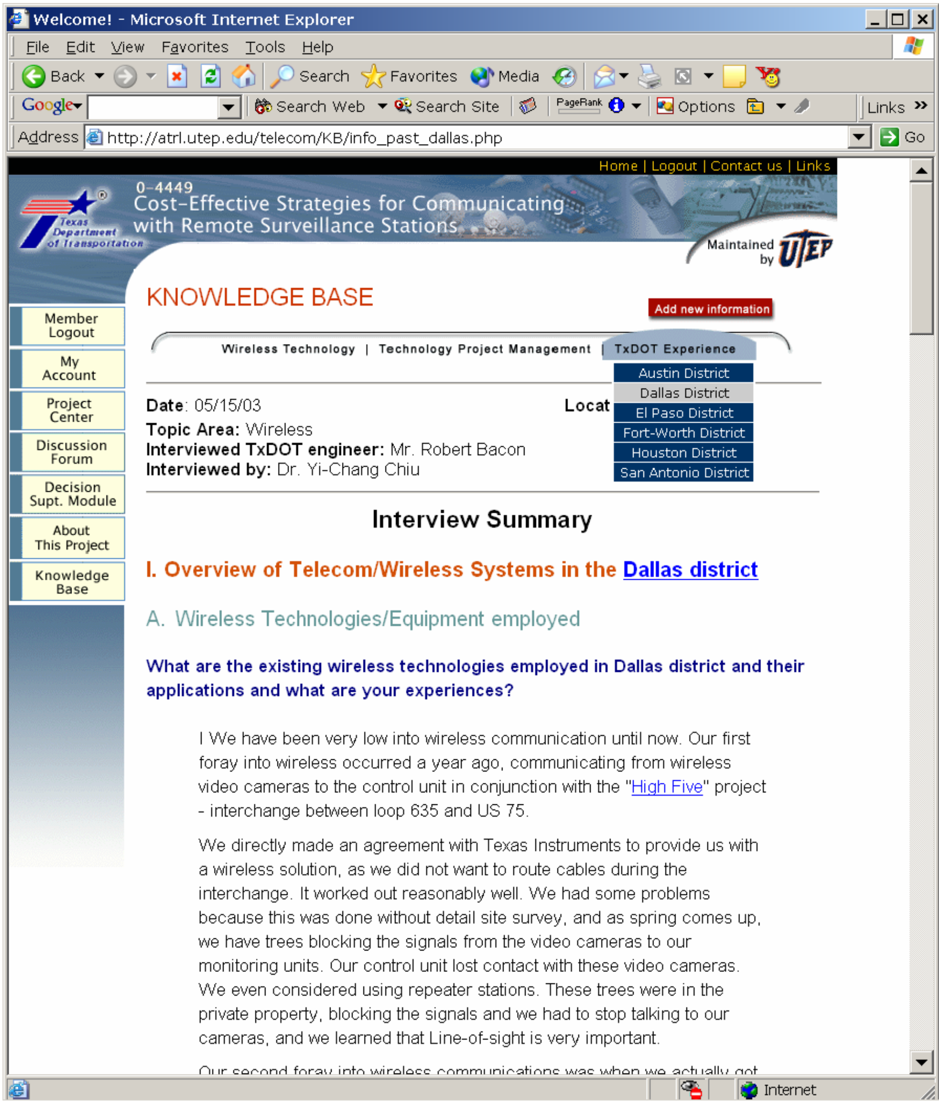

Figure 5-14. TxDOT experience – interview summaries.

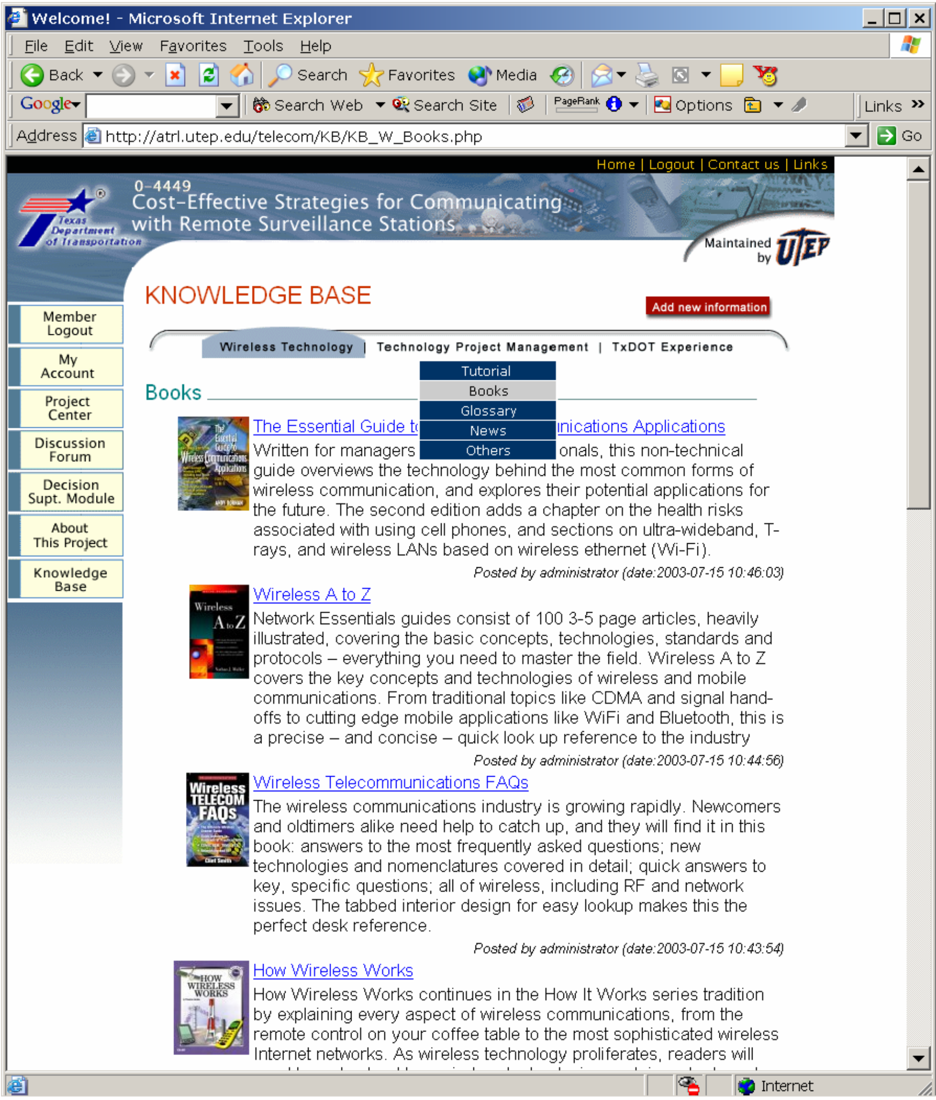

Figure 5-15. Books *section in* Technology Project Management *in knowledge base.*

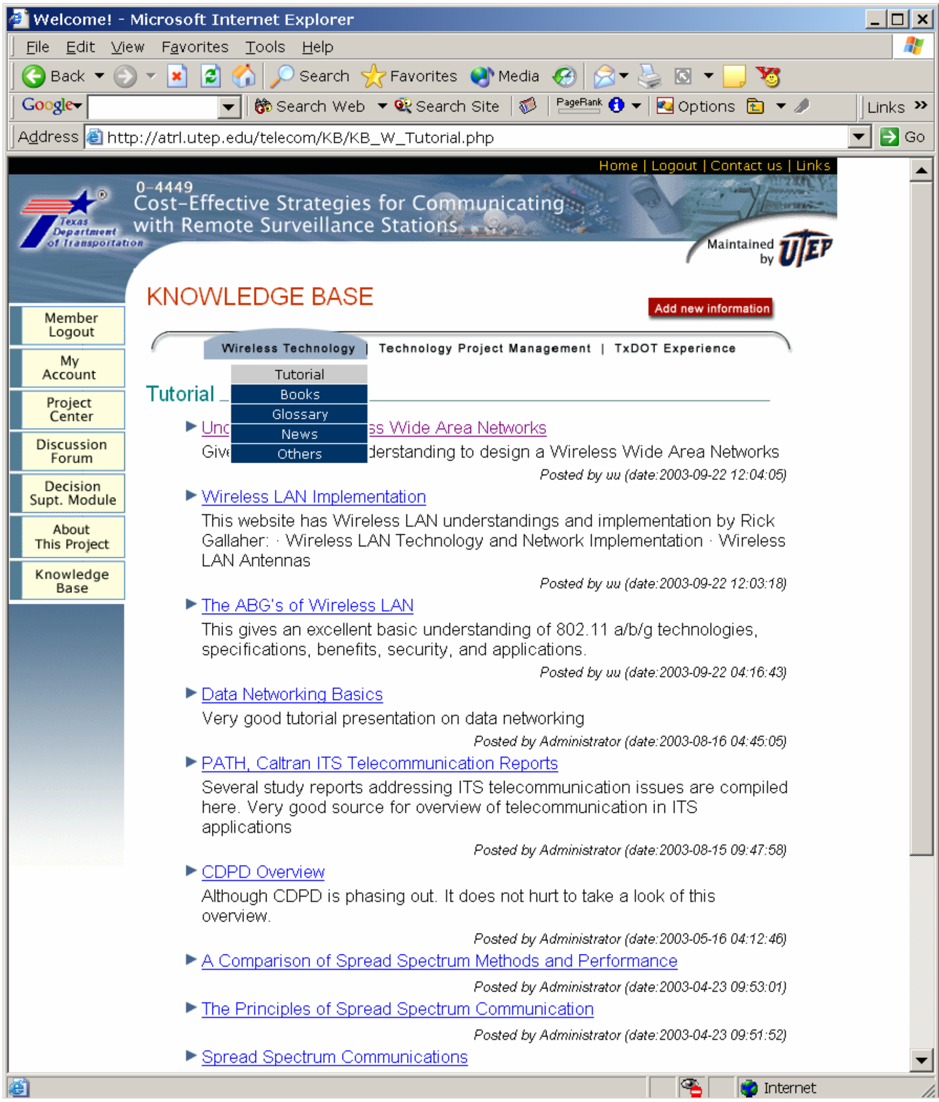

Figure 5-16. Tutorial *section in* Wireless Technology *in knowledge base.*

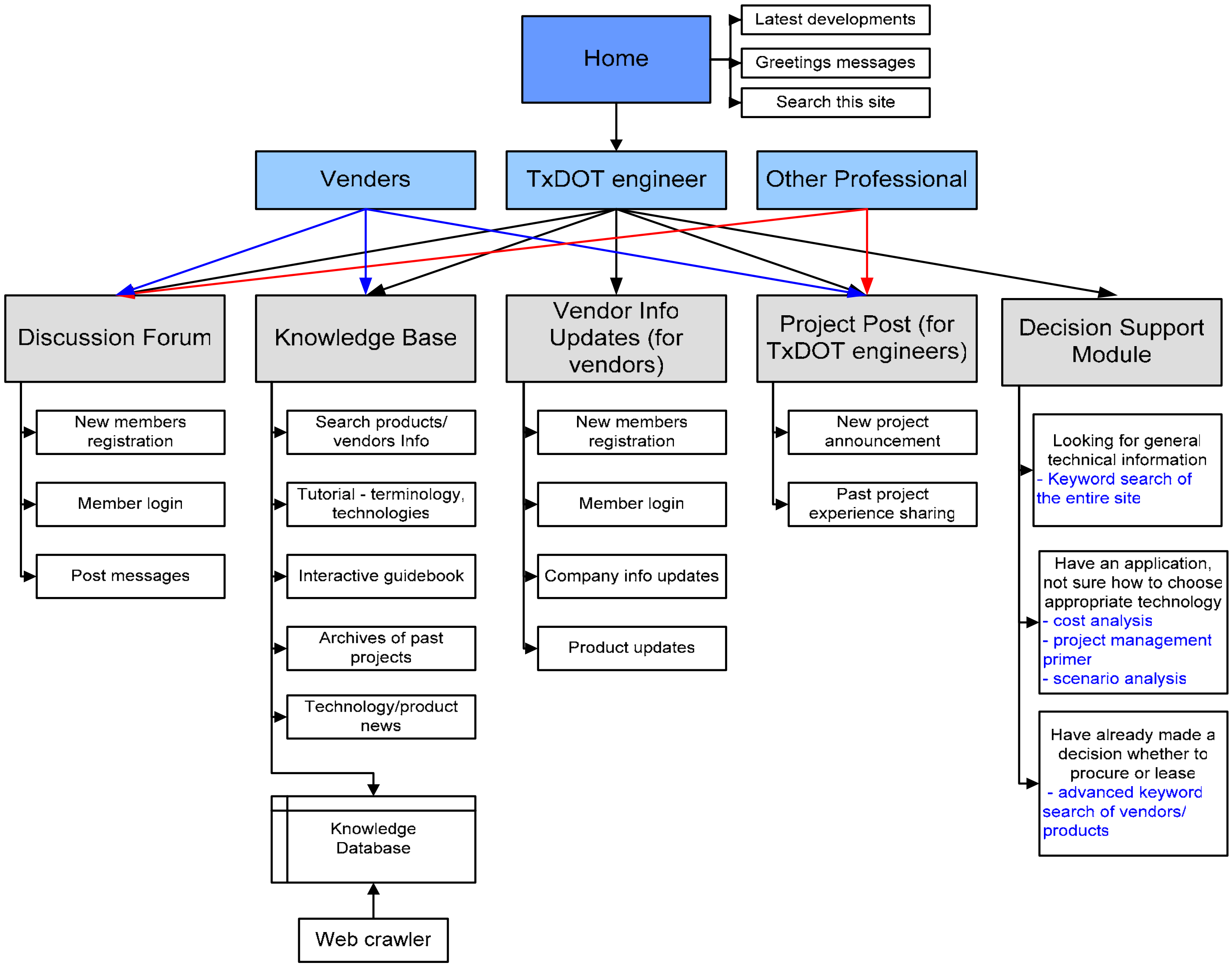

Figure 5-17. Web-based knowledge management system structure for wireless technology acquisition

Chapter 6. Summaries and Concluding Remarks

While major installations to support advanced traffic management applications are being deployed along the state's major urban freeways, the need for surveillance and detector capabilities also exists in numerous remote locations with no established telecommunications capability for the transmission of roadway-related data. The abundance of available communication technology choices, ranging from the decades-old but robust technologies (e.g., analogue radio, spread spectrum radio, microwave, etc.) to the state-of-the-art and soon-to-be-available technologies (e.g., 3G cellular wireless), presents difficult challenges for traffic engineers in deciding upon a cost-effective means of data transmission from a remote location to a freeway traffic management center.

In reality, not all technology options are suitable for the desired application. In conjunction with the application, the availability of site characteristics such as power, line of sight, transmission distance to adjacent relay/receiving site, transmission data rate requirements, frequency, bandwidth, and more will determine the range of options available and generally point to a specific technology choice. Furthermore, for a particular application multiple communication system configurations that satisfy the application's functional and physical requirements are likely to exist. Different configurations involve distinct wireless or wireline technologies. Under such circumstances, choosing the most suitable configuration/technology becomes challenging for TxDOT engineers.

In summary, this research project has accomplished the following objectives:

Documentation of the state-of-the-practice and past experience in designing wireless communication system configurations, identification of deficiency of current practice, and survey of commonly encountered issues by TxDOT engineers.

Survey of prevalent and emerging wireless technologies and investigation of future impacts of wireless technology to traffic operation and ITS applications.

Development of an effective approach to characterize available communication technology choices and analysis of how they can be applied to various traffic operations applications. A particular accomplishment has been made to develop guidelines to facilitate the decision-making in choosing cost-effective and minimal-risk communication technology given the operational requirements and decision objectives.

Design and implementation of a Web-based knowledge management system (WBKMS) to facilitate the formation of institutional knowledge, and to enable on-line learning of applications vs. communication technology choices, as well as continual updates of wireless technology.

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Appendix A—TxDOT Engineer Interview Summaries

A.1. Dallas District

Date: 05/15/03 **Location**: Dallas

Topic Area: Wireless
Interviewed TxDOT engineer: Mr. Robert Bacon
Interviewed by: Dr. Yi-Chang Chiu

I. Overview of Telecom/Wireless Systems in the Dallas District

A. Wireless Technologies/Equipment Employed

What are the existing wireless technologies employed in Dallas district and their applications and what are your experiences?

We have been very low into wireless communication until now. Our first foray into wireless occurred a year ago, communicating from wireless video cameras to the control unit in conjunction with the "High Five" project - interchange between loop 635 and US 75.

We directly made an agreement with Texas Instruments to provide us with a wireless solution, as we did not want to route cables during the interchange. It worked out reasonably well. We had some problems because this was done without detail site survey, and as Spring comes up, we have trees blocking the signals from the video cameras to our monitoring units. Our control unit lost contact with these video cameras. We even considered using repeater stations. These trees were in private property, blocking the signals. We had to stop talking to our cameras as we experienced the importance of Line-of-Sight.

Our second foray into wireless communications was when we actually got two wireless video camera units from David in the Austin District, which were originally purchased for the Corpus Christi district. As part of this interchanging, we mounted these cameras on 100 feet high mast poles with a ring. The concept about this ring is that you can mount the cabinet unit, the dish and the necessary equipment onto it. You can lower the ring if you need to work on the cabinet or the unit. Once the ring is raised to the top and after the necessary repair, the unit gets plugged in, the cameras are turned on and they communicate with our control center across the street. It worked very well for us. Now, we have two wireless video cameras on high mast poles recording information and transferring information wirelessly to our control center situated across the street. In situations where we have to do major interchanges, we might find it very difficult to have many control centers. So, what we plan to do is to have 100 to 150 feet high mast poles and mount the cabinets, radio and camera equipment. Now, instead of communicating with the control center from the cameras, they will communicate with a cabinet mounted across the street. From this cabinet the information will be transferred through the fiber. This was a test project and has worked better than what we expected. Still, We are looking for other wireless technology application opportunities.

Another project that is under construction for material acquisition is a microwave speed detector. We were going to use CDPD modems; however, According to AT&T, CDPD is going to be obsolete in another year and half. Therefore, we are working with our contractors and service providers so that we get the right modems that will be supported in the next generation of communication technologies.

We want to generate a speed map for the Dallas district. We have 46 locations in the Dallas counties. Due to funding issues, we could not have the stations ideally spaced. The stations are situated with an average distance ranging from 3 to 5 miles. We needed to provide an effective speed map to the public because they are more interested in knowing how the traffic is moving. So far, we are using microwave and CDPD to communicate with the units. The advantage of this is that the units are actually solar powered; you can dig a hole anywhere put the pole and mount the units. This is like a modular type solution, where you can add and remove the detectors as necessary with little difficulty. This is stage one and if this works well and have reliable wireless communication, we will probably try to expand the system and fill in the gaps.

Up to this point, this is our experience with wireless and its applications. Our problem with wireless is the ongoing saturation of unlicensed frequencies. Frequency availability is always an issue if you want to get a licensed bandwidth. There are a lot of wireless systems around. That is one of the reasons why we have not extensively employed radios. Nonetheless, we see this is the right direction to go because it is a cost effective and flexible way to communicate information to radio stations. Other districts like Fort Worth have been pretty successful in that.

Is working with service providers to overcome this problem, a possible option?

We had some discussions with Fort Worth for two months about service providers providing redundancy. My administration itself thought it was too costly to be able to provide a redundant leg. How much is it worth to have this technology in place, because if a fiber gets cut you are going to wish you had this alternative. It is difficult to answer this question with the state of affairs we are currently in. With the 10 million dollar budget crunch it is hard to say. It affects the operational budget and it becomes difficult to pay the service providers year round. That is why we prefer projects with the capital budget like providing more fiber links to the existing ones, which would be here for a while.

How do you justify the costs occurred with the equipment being non-operational or obsolete?

It is very hard to argue that. We, engineers, constantly encounter situations in which hardware or software is no longer supported by venders, incompatible with other upgraded or newer systems, or difficult to maintain. In fact, it is very difficult to foresee such situation when the technology acquisition decision was made years ago. When it comes to the decision in which equipment needs to retire (regardless it is still operational or not), we have challenges in justifying that suggestion to our administration.

You brought up an important issue which concerns with the "Life-Cycle Cost and Benefit" of technology investment. Given the rapidly innovation in technology, every technology acquisition decision come with a considerable risk of having to retire the technology investment even they may be still functional. This also highlights the importance of conducting a "Life-Cycle Costing" analysis for making such decisions. It is one of the objectives of this project to generate general guidelines in that regard (Chiu.)

B. Lesson Learned

As said earlier, not to do site surveying for line-of-site for wireless communication equipment in winter is a lesson that we learned. I personally felt that talking to other engineers in the state is a good way to get information and learn from others. However, there have been limited opportunities to facilitate such interactions. Going to conferences or meetings is a good way but not quite efficient. I have envisioned long time ago that TxDOT division should develop and maintain some kind of discussion forum to let us talk to other engineers but it has not happened. We have learned many lessons in a hard way.

C. Future Deployments

We have a master's student from the Computer Science Department interested in doing his thesis in Wireless ATM networks. Dallas district has an ATM network, so does Fort-Worth district. His thesis was based on putting remote wireless links as redundant paths.

One of our projects is to have a wireless ATM link between Dallas and Fort Worth districts. We do have a fiber link right now, but if you sustain a fiber cut the network is down between the two districts. What we are looking for is a redundant wireless link, so that if we ever sustain a fiber cut we still have the network up and going. We have not gone very far on this, but we are interested in pursuing it. We have ATM switches spread throughout the county. We do not have redundancy right now, but when we have the complete system we are going to have it completely redundant.

II. Suggested Features for the Clearinghouse

There are people with a lot of information, but might not be willing to share their knowledge with the presence of strong willed people around them. They might feel intimidated by them or afraid of looking bad in a group meeting. Online discussion forums would be a good place for them to share their knowledge, ideas and experiences without having to feel intimidated by anybody. Their input could really help this website gather information which is more useful to the engineers in the field.

Do you suggest the users in the discussion forums to be anonymous?

It is nice to know the people who are involved with that kind of work. From our Stand point, if you know the person who made the post on the discussion forum, you can always call that person and talk to him and share his opinions and experiences. At the same time, being anonymous is good because it is hard to argue with the strong willed people.

Our website can be accessed via a username, selected by the user when he fills out the registration form. We have a database which keeps track of all the users, without having to reveal their information if they do not desire to do so (Chiu).

Who is going to manage this discussion group to make sure topics do not get off-line? (Robert)

We will work to identify a few engineers in TxDOT who have the kind of personality to manage this and willing to do it. We, the research team, will strive to push and maintain the website at least for a good period of time, and hopefully the forum will grow and evolve by itself. We would like the discussion forums to grow and be managed by the TxDOT engineers.

This website will be very beneficial, if you can periodically email these questions to a technical group of people who can answer them from time to time. I have used this kind of system very often. If I know a person is working on a project of my interest, I would straight up call him and try to share his opinions. It would be nice to portray engineers from big districts as approachable to the engineers from smaller districts.

We would be having a Technical support panel. When the engineers register, we would be asking them if they are willing to be a part of our technical support panel. We email some of the unanswered questions to this panel periodically asking if they are willing to answer them. Definitely you will be part of our panel group?

Yes. That is a good idea. You can reach out to more people and say we need your help with this question and make them more involved with the discussion forums. I have a good technical staff and they can answer the questions from discussion groups and can be a great benefit to your discussion groups.

A.2. Fort Worth District

Date: 05/19/03 **Location**: Fort Worth

Topic Area: Wireless radio
Interviewed TxDOT engineer: Billy Manning
Interviewed by: Dr. Yi-Chang Chiu

What would you need and how would you expect our product response to be?

An interactive model, i.e. Decision Support Model, is designed to help find products for specific applications using attributes like wireless transmission range, bandwidth, frequency of operation. This would help the engineer make a decision in selecting the right product suitable for his application.

Give us an insight into the type of technologies and equipment employed by TxDOT in Fort Worth.

We have been using Microwave system for the past 8 years for video and data transmission. We are also using Spread Spectrum Radios, 31 GHz radio, video and data using RS232, video on T1 in the unlicensed frequency bands. 2.4GHz radios in the licensed frequency band from ranger are being tried to transmit video over short distances. Presently 900 MHz Frequency Hopping Spread Spectrum radios are being used to pass video and data for applications such as camera control, sign communications etc. It takes the signal from a close contact and converts it to analog signal at one end and on the receiving end it is again converted back to close contact. For long distance communication, we are trying to get the Ethernet radios work for transmitting video and data rather than just data.

Microwave System Employed

Our Microwave system was purchased from Texas Microwave Systems for point to point to communication of video signals over a range of less than a mile. It has been in place for the past 8 years. We had no video cameras back then and could not deploy them because of the interchanging and construction going on in downtown. So, we reached an agreement with owners from a tall building located downtown and mounted our equipment. Ever since our microwave system has been transmitting and receiving video signals, there has never been a failure. It was very stable in all kinds of weather conditions. One of the receivers got a little damaged, but the system still works fine. The two drawbacks were that it was expensive and that it functioned in the licensed frequency band. Although the unit is standalone, it has been integrated into our system. This system runs over 5 miles on US-35 and drops down onto the fiber at that point. This is the last link, but it is tied directly into our fiber on the receiving end. Everything we have used is integrated with our whole system. This was the first wireless communication system we have had for a specific application.

Spread Spectrum

We needed the ability to use radio and stretch out further beyond the point we are right now in terms of bandwidth and cost. Although microwave was a very stable system, it was too expensive and it was not easy to move it from location to location. At that point we had money and we were looking for something that was very well suited for our application and would do the job perfectly.

In fact, we have one of those radios mounted right now upon the North Texas Intercouncil Building and shooting back video signals to our control unit. We have been able to use it at different locations to transmit video and data. Right now, its main purpose is to take a video tour of Dallas and feed it to the card, so they can view and know what is going on.

T1 Video

Although we had the T1 video for a while, it was never installed in the field. We never got that far. Full Bandwidth video not only expanded our video system, but also our data communications because it supplied all the channels. Those radios have been very reliable.

We have nearly 2000 roadway loops in the ground and we have stopped maintaining them. Instead, we started to replace them with overhead detection with RTMS. We tested 900MHz Incomm radios for a good with no problem. We are using 20 other radios at different locations with 26 RTMS to bring back the data through he radios to the cabinet and kinking it back over to close contact. RTMS does serial data. We are trying to move out radios that won't use serial data. We are trying to make the 900MHz radios work for video transmission. We worked with the vendors of the codes we are using and made configuration changes to make RS232 radios work for video. It came down to that the codec s we are using won't work with RS232 data because of the low bandwidth i.e. 115kbps, not quite good enough to get good quality video on a continuous slow stand basis.

We found dispatching data on RS232 extremely reliable, very easy to deploy and started using them for signs and camera controls. We cannot get messages to our signs fast enough because our signs are dial-ups and it takes at least 15 minutes to get our messages onto the signboards. So we started looking at 900MHz and extend our fiber to get our messages instantly onto the signboards. These radios were flexible, easy to use and low cost and could be used for point-to-point; point to multipoint or to drop to a fiber etc. Our 900MHz radios were from bought a Canadian company Inncom. It permanently leased us the antennas for these radios.

Would you give us some of your vendor information and your satisfaction level with their products?

We had 2.4GHz radios from Ranger telecom for video transmission. It was setup in South Arlington by our guys. We didn't get clear signals for nothing and we changed locations where we had a very clear line-of-sight with no interference and less than a mile apart and still could not get any signals. When the technical people form Ranger Telecom looked into the problem, they came up with the report that the area was saturated with signals in that frequency and hence could not receive any signals. They tested their 5.8GHz radios and they passed with flying colors.

A.3. San Antonio District

Date: December 16th, 2002 **Location**: San Antonio TMC "TransGuide"

Topic Area: The telecommunication systems in TransGuide
Interviewed TxDOT engineer: Mr. Brian Fariello
Interviewed by: Haitham Logman

I. Overview of Telecom/Wireless Systems in the District

A. Wireless Technologies/Equipment Employed

The most recent project is expanding TransGuide by adding a 9.1 miles of the US90. This project started in January 2000 and ended in June 12, 2001. The contractor for this project was Mastec/M.E.Hunter and the subcontractors were Telemetrics (for CCTV), FDS and H.C.I. (Fiber optic for LCS and VMS). The budget for this project was $11,043,000. Around 35% of this budget (approximately $3.9 millions) was dedicated to the design and construction of the communication system. The section has stretched from 0.79 west of loop 410 to Loop 353 (Nogalitos). This expansion was able to provide TransGuide with surveillance and control over the US90 adjacent to Wilford Hall Military Hospital, Nelson Wolfe Stadium, Kelly Field, and Lackland Air Force Base. This expansion includes installation of CCTV, Inductive Loops, Dynamic Message Signs (DMS) and Lane Control Signals (LCS). The equipments installed in US90 were 9 CCTV cameras, 8 main Lane Control Signs, 10 frontage road VMS, 21 LCS, and 250 inductive loop detector stations. Data, voice and video is transmitted from this expansion project. The traffic management engineer, Brain Fariello has estimated the need for approximately 155 Megabytes/sec bandwidth to transfer data from the field devices. Brian has also provided a list of the equipment purchased for this project to the research team.

TransGuide has scheduled three more expansion projects on highways: (1) Loop 410 (US90 to Culebra Rd and then from Culebra to Ingram Rd), (2) US281 (Basse Rd to Nakoma), (3) Loop 1604 (NW Military to Bitters Rd and then from Bitters Rd to US281).

From 2000 up to date TransGuide have installed the equipments in Table A-1.

Table A-1. Installed equipment at TransGuide.

Sensor/Equipment	Installation	Application	Medium
CCTV	32	capture live video images from the freeway	Fiber Optic lines *
LCS	24	control and assign lane availability	Fiber Optic lines *
Main lane message singal	51		Fiber Optic *
Frontage Road Message Singal	61	post messages to motorist about traffic conditions	Fiber Optic lines *
Inducitve loops	442	collect traffic conditions (speed, occupany and volume)	Fiber Optic lines *

B. Lesson Learned

1. Write about the strengths and weaknesses of the technologies/equipment used for their particular purposes. Their experiences with the system in satisfying the expected needs. Efficiency of the equipment.
2. Include the lesson is the decision making process
3. Concerns and existing issues

C. Future Deployments

There is a major project underway conducted by Southwest Research Institute (SwRI) to define the requirements and develop a high-level architecture to upgrade San Antonio TransGuide and Houston TranStar. The SwRI proposed using the ATM technology as the future backbone of the network replacing the SONET technology currently deployed. The ATM technology has been selected because it could deliver guaranteed QoS and hardware multicasting required for TransGuide video, bandwidth-efficient redundancy for effective backup and restoration, and support for Ethernet end devices for general data that did not require ATM's features and cost. SwRI have also selected the SNMP for network management because it was the only protocol that offered centralized management of an entire diverse network was flexible and well a supported standard. In addition, this protocol has numerous products offering by vendors. Lastly, the SwRI have selected voice-to-IP for voice communications because it had a strong and growing number of products.

II. List of the Contractors/Vendors

Contractors:

1. Mastec/M. E. Hunter AlliedSignal Technical Services Corporation
2. Georgia Electric Company
3. Hypower Inc.

Subcontractors:

1. CCTV Cameras: MZB Video Solutions
2. Fiber Optic Communications Network: Lucent Technologies (Formerly AT&T)
3. Message Signs / Lane Control Signals: Mark IV Industries
4. Fiber Optic Communications Network: Lucent Technologies
5. Fiber Optic Communications Network: C&C Networks / San Antonio Telephone
6. CCTV Cameras: Telemetrics
7. Message Signs/Lane Control Signals: Fiber Optic Display Systems (FDS)

III. Other Suggestions

1. Young engineers should understand in depth the high level architecture of the standard they use before selecting any equipment as the diagram in Figure A-1 illustrates.

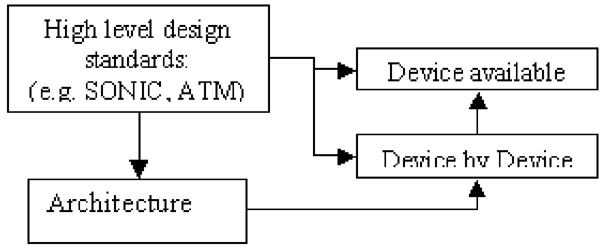


Figure A–1. High level architecture

2. It will be a good idea if TxDOT can develop a facility that is responsible of testing the products that vendors provide. This will enable engineers to utilize well tested products instead of accepting performance of communication systems that is provided by vendors' salespeople.

A.4. Houston District

Date: 02/24/2003 01:30 pm **Location**: Houston Traffic Management Center (TranStar)

Topic Area: Telecommunication devices and techniques
Interviewed TxDOT engineer: David Fink and John Gaynor
Interviewed by: Haitham Logman

I. Overview of Telecom/Wireless Systems in the District

A. Introduction

TranStar utilizes different wireline and wireless systems to communicate with offsite devices. Most telecommunication devices used by TranStar are geared toward managing traffic conditions in different ways. This entails different objectives such as traffic surveillance, incident detection, flood watch, communication with other city agencies, and information dissemination to drivers. The TMC disseminate the traffic conditions, real-time traffic maps, personalized Alerts, wireless web, emergency road closures, roadway weather sensors, regional construction, TxDOT lane closures, emergency information, transit information, HOV lanes, commuter and Bus Services.

B. Wireless Technologies/Equipment Employed

The Houston TranStar employs the following devices:

- CCTV: with pan-tilt-zoom capabilities. Data is transferred though fiber optic lines using an analog switcher.
- 110 Dynamic Message Signs (DMS): data is transmitted to DMS via fiber optic lines plus a typical telephone line (Modem). Currently the system employs products of three different manufactures.
- Inductive loops: the inductive loop was designed in Austin and uses fiber optic lines and satellites. The total network is 200 miles of fibers: 36 single and 36 multiple.
- Lane Control Signals
- 120 Ramp meters units: data is collected using vivid sensors to the TMC, then the TMC transmits the data to the Lane Control Units (LCU) though fiber optic lines.
- Vivid sensors
- Weather surveillance radars such as the WSR-88D can detect most precipitation. The Harris County deploys multiple weather detectors that are mainly PT and flood gauges. The data collected are transmitted using Radio Frequency with repeaters to the TMC. The transmission is done every five minutes. Due to the proximity among transmission towers, the Harris County utilizes identifiers to differentiate between signals transmitted.
- Highway Advisory Radio (HAR): on channels 1610 AM and 1680 AM. It uses telephone lines to transfer voice data to radio towers that transmit traffic and advisory information to three mile radius.
- Automated Vehicle Identification: used for toll collection, and uses unlicensed short-trip spread spectrum, then transmission through telephone lines using modem. This activity cost the TMC a $12,000/month.

C. Lesson Learned

- Engineers acknowledge the need to move for digital system that is mainly based on ATM standards. The current analog system is phasing out, and less support is expected in the long run.
- Unfortunately, TranStar engineers do not think the switch to ATM digital standards is coming this year or the next few years.
- Sample of the products are usually supplied by the contractor to the TMC for approval. The TMC approves products as things show up.
- The two major concerns of the TMC are to (1) install products that are compatible with other systems (interoperability) and (2) avoid systems that have unique vendors
- Engineers are not currently using portable message signs at construction sites but are aware of some testing endeavors by construction contractors.
- Engineers think that the CDPD system will be supported after the end of 2004. The current service is provided by Verizon.
- Engineers are anxious about the frequent change of licensing by the FCC.
- Traffic and weather data are transmitted to the TTI website (Texas A&M) using point-to-point wireless microwave.
- The fiber line that is used for different applications is owned by TranStar. The current TranStar fiber optic lines have no redundancy and rerouting capabilities. Therefore, cuts on these lines are major problems that the TMC struggling with, especially on suburban areas where new developments and utility lines are extending. In some freeways, the Harrison County has their own fiber optic lines such as the I-610. Currently, there is partnership between the County and the TMC to distribute the transmission cost of these fiber optic lines. This sometimes causes conflict between the federal and state budget responsibility to maintain the fiber lines.
- The fiber optic lines are so expensive. For large areas, the cost can go up to three million per thousand feet.
- The density of radio signal causes some interruption of radio services. For example, one of the HAR towers is repeatedly interrupted by a station that works at the same bandwidth in Orlando, Florida.

II. Suggested Features for the Clearinghouse

- TranStar engineers prefer not to receive any offers directly from vendor's sales people. So a recommendation is to design a one-way communication from TxDOT engineers to vendors. Actually, in TranStar, projects are designed by TxDOT engineers. The specifications of these projects are then transferred to the selected contractor. The TMC accept the lowest bid as long as it satisfies the specifications and the minimum requirements. Contractors are free to choose their equipment vendors provided that minimum specifications are met. This scenario suggests allowing telecommunication contractors to access the website and contact vendors.
- Engineers are aware of the rapid change in technology and are interested in exchanging the experience and understanding what other districts are employing.

A.5. Austin District

Date: 05/24/03 **Location**: Austin

Topic Area: Wireless
Interviewed TxDOT engineer: Mr. Brian Burk
Interviewed by: Dr. Yi-Chang Chiu and Mr. Haitham Logman

I. Overview of Telecom/Wireless Systems in the District

A. Introduction

Our project is basically aimed at helping the TxDOT engineers in selecting cost effective wireless communication strategies for communication with remote surveillance station. It is not required to be remote; it could also be a mobile unit. Presently, fiber technology has been employed in most of the districts and it is difficult to use fiber in some remote locations and very expensive as well. Wireless communication is a newer technology; it makes communication much easier in remote locations, in adverse weather conditions and has more applications compared to the fiber technology.

B. Wireless Technologies/Equipment Employed

We have used Telecom for sending voice data and video, typically localized over a twisted wire pair and transferred onto fiber optic lines. The only Wireless telecommunication implementation has been cellular phones with data capabilities to access low speed data for system control units like wireless laptop to control and monitor things. We are trying to apply the same application to vendor related software's like DMS. (*) Right now, we are having a problem with the telephone service provider over hardware and software interface. Lot of vendors coming up with new products is not supporting our legacy operating system Windows NT.

The other problem is TxDOT software has been designed for DOS and the new products with very nice features; unfortunately, they do not work with our software. We use wireless air cards to put in our laptop to control and monitor remote units. Windows NT and our older software's do not support these newer products and we have run into some problems. If our network goes down, we lose our Ethernet capabilities. The fallback is DOS, which is reliable and gives us the flexibility to maintain the highway systems in times of network failure.

What are the type control devices that are being used in the district?

The equipment that is being controlled is Vehicle Detector, Dynamic Message Center, lane control signals, Highway advisor radio transmitter, Closed Circuit Television and other typical road side ITS type devices. Most of the detectors are loop detectors. The control of these detectors and lane control signals are done by the department developed software and hardware. (*Page 2) Client server software integrated to control other devices, like CCTV, LCU, SCU, etc. is designed to control these devices exclusively or relying on a central control device unit, like the CCTV which is controlled by a third party software that runs on a workstation.

Typically, all our equipment is address based type, all are based on RS232. Since addressable, we can multi-drop on one RS232 communication channel and keep those channels separated by protocols. We put as many cameras as will work on RS232 channel for that protocol.

In Austin district you have a fiber link. What are the control devices that are hooked up by the fiber?

Generally, we employ a hub and spoke type of topology. We run a fiber optic trunk link called hub enclosure, typically a 8 x 12 concrete building (~). From there, most of the telecommunication is over wired. We have twisted wire pair to a number of cabinets and also to a number of cameras. In a hub enclosure we never put in more than four LCU's, four CCTV's, and four DMS. This seems to maximize the capacity of our hardware and software.

The only exception is the video data from the cameras. It usually comes to the hub over fiber and is moved it to electrical transmission right at the pole. It comes down the pole over a coaxial cable and when it gets it to the cabinet at the bottom of the pole, we have a fiber optic transmitter that turns it to optical energy and sends it to the hub building over the fiber.

The first system we deployed is a hybrid trunk system, where cameras were dedicated to the fiber and soon realized that requires a lot of fiber for our 400 odd cameras. So we looked for a product that could integrate both voice data and video data over a single network topology. We found a SONET equipment manufacturer that could integrate voice and video and meet all our existing hardware and software requirements. That is what we are deploying now.

We initially deployed T1 line for our data. We had copper T1 units coming out of this T1 line and fed it to data fiber optic transmitter and then put it on an optical line. It was not integrated with the multiplexing device. Now the manufacturer has come out with an integrated solution for us if we chose to use it, but our system works without it, so, it is fine. Our move to SONET did not need many changes to our existing system. The DSL that we used for different protocols on RS232 were exactly the same. We divide things up into 24 channel banks for a T1 and those are put into virtual tributaries with our standard site protocols and things were pretty uniform regardless whether you are on a SONET or a T1 network. The only difference on the SONET is that fiber optics is all integrated into their solution box. The video from the camera still comes in from the Transmitter at the pole, only now when we get to the hub, we have to go into a receiver to put it back into electrical energy and then put it onto the input of the fiber optic transmitter. This transforms into optical energy and combines with all other data and sends it over the trunk to the central unit.

How many cameras and DMS do you have?

Right now we have about fifteen and will increase in the future. Also, we have around fifty cameras on file. They increase by probably a dozen every year. We have plenty more cameras at our center for testing equipment. Currently, we are running 100x100 matrix. Each of our SONET nodes acts as a 8x2 matrix switch in the field with 8 output switches at the center.

Some limitations for SONET is that we do have our broken up by a corridor. At the center, we have Multiplexers that switch 8 inputs of video per corridor. Basically, we have four corridors Austin IH 35, 183, US-290 and loop 1. Right now, we transport the video data from US-290 via Austin city, as our infrastructure doesn't go that far. So our OC3 data in the field is passed to the city of Austin, we have a node for their network here and get it off that node. They cannot download our video data, since everybody encodes it differently depending on whatever type of transmission they use. Thus, our local partners are able to interact with each other at OC3 level.

Right now we do have one Closed Circuit Television that is operational and we have more coming up, probably this year or early next year of dialup ISDN CC TV, because we do not have the ability to put fiber optic infrastructure. There are places like the downtown where some sort of reconstruction is going to take place. In all the alternatives we have looked at we cannot have our infrastructure and not have the existing system disturbed.

We are looking to install inexpensively other technologies such as broadband ISDN, wireless technology etc for these areas. Typically, we need something with a bandwidth less than broadband. Right now what we are using for our video is a motion JPEG at 12Mbits/sec. We looked at 6Mbits/sec and the driving factor is our partnership with the media stations. They simply do not want to broadcast video over their network unless it is close to full resolution or full frame rate video. We have seen 6Mbits/sec MPEG II technology, which appears to be same or better quality than 12Mbits/sec motion JPEG. The vendor notices and is in the process of changing their technology. We are inclined to stick to technologies that are close to the existing standards. The compromise comes in when you are trying to integrate something with your system. The other big criteria these days is that, with the size of the system and the resources needed to manage this system, it is important to have these things integrated into the existing system.

Do you a routine data feeding method to the media?

Each one of our network affiliates here has a broadband connection to our switches. We provide them with analog outputs. However, the way they want to get the data back to their station is up to them. We have one provider that is doing it over T1 lines and providing one of our affiliates and the rest of them mostly use fiber lines from BELL.

Do you give them the tool to edit the video?

The control for the video is done by third party software. We suggest the software to our affiliates and advise them to follow a protocol. It is then up to our affiliates to take action. We are trying to develop software to control the video, so that our network affiliates can advantage from that.

In your center, what kind of data do you typically store?

We do not record video information. Still, when we started, the product that we use allowed us to log things on that video network communication’s controller. User can log on and log off, and do things on the system. But our contractor had problems maintaining these communications, eventually, we were not able to get it resolved and had to cut it off.

With the increasing popularity of IP based networks, do you see Austin moving towards making everything IP based?

We do not have enough resources to experiment. We would let other districts like Houston and Dallas, try and experiment. If we think it would be useful for us, we may move towards that goal.

Do you typically communicate with other districts on some of the technical problems you face?

If we have a problem and we think some other districts ran into the same problems, some communication flies around, but not on a regular basis other than the yearly meeting. We find it very helpful and the administration supports it

Appendix B—Data Rate Requirement for Traffic Management Applications

Table B-1. Lane-by-lane, station, and segment data transmission characteristics.

Coverage Area	Number of Sensors	Polling Interval (s)	Unit Data Size or Object Size (bytes)	Number of Bits Transmitted (kbits)[1]	Transmission Rate to Transfer Data in 1 min (kbits/s)[2]	Transmission Rate to Transfer Data in 30 s (kbits/s)[3]
Lane-by-lane	3,000	30	170	4,080	68	> 150
Station	3,000	30	40	9.6	16	> 50
Segment	300	30	50	120	2	> 5

[1] Number of bits transmitted = Number of sensors × unit data size × bits/byte = 3,000 × 170 × 8 = 4,080 kbits for lane-by-lane sensor data.

[2] Transmission rate to transfer data in 1 min = Number of bits transmitted/60 s = 4,080/60 = 68 kbits/s for lane-by-lane sensor data.

[3] 30-s data transmission rate > 1-min data transmission rate × 2 > 68 × 2 > 150 kbits/s for lane-by-lane sensor data. The 30-s data transmission rate (i.e., throughput) is greater than twice the 1-min data transmission rate because a guard band is added to ensure that the previous 30-s data transmission is complete before the next 30-s data transmission begins.

Source: Communications Network High Level Design Document, Draft, *Task 19* in *Southern California Priority Corridor Intermodal Transportation Management and Information System (SHOWCASE) High Level Design*, Iteris and NET, March 6, 2000.

Table B-2. Transmission rate for various data and video requirements.

Data and Video Requirements	Information Requirements of Strategy	Data Transmission Rates on the Network (kbits/s)	Composite Data and Video Transmission Rate (kbits/s)
High data, no video	Receive regularly updated lane-by-lane congestion, event, and traffic signal information	*Multi-region* Lane-by-lane: 448 Events: 5.3 Arterial signal: 352 50% margin:[1] 403	1,208 scaled up to 1,544 [2]
Medium data, no video	Receive regularly updated station, event, and signal information	*Single region* Station: 34 Events: 5.3 Arterial signals: 176 50% margin: 108	323 scaled up to 384[2]
Low data, no video	Receive regularly updated segment and event information	Segment: 13 Event: 5.3 50% margin: 9	27 scaled up to 56[2]
High data, high video	Receive regularly updated lane-by-lane congestion, event, and traffic signal information plus video on two T-1 lines or equivalent	*Multi-region:* Lane-by-lane: 448 Events: 5.3 Arterial signal: 352 50% margin: 403	Data: 1,544[2] Video: 3,088[3]
High data, medium video	Receive regularly updated lane-by-lane congestion, event, and traffic signal information plus video on one T-1 line or equivalent	*Multi-region* Lane-by-lane: 448 Events: 5.3 Arterial signal: 352 50% margin: 403	Data: 1,544[2] Video: 1,544[3]
Medium data, low video	Receive regularly updated station, event, and signal information plus one video image at 384 kbits/s or two images of less quality	*Single region* Station: 34 Events: 5.3 Arterial signals: 176 50% margin: 108	Data: 384[2] Video: 384[3]

[1] 30% margin for growth was applied in reference [1]. However, here a more conservative 50% margin is used. Margin requirements may vary from the value shown depending upon the maturity of the communications network design (e.g., anticipated growth in the number and types of devices controlled or supplying information), the planned expansion in the size of the managed region, and forecast population increase.

[2] Transmission rate of nearest standard communications media.

[3] High video transmission rate set equal to 3,088 kbits/s, medium to 1,544 kbits/s, and low to 384 kbits/s.

Source: Klein 2001.

Table B-3. Data types and transmission rates for selected traffic management applications.

Application	Data Types	Unit Data Size (bytes)	Refresh Time (s)	Number and Type of Data Units in Network	Transmission Rate[1] (kbits/s)
Gather region-wide sensor data	Mainline and ramp meter data	Lane-by-lane: 170 Station: 40 Station: 40 Segment: 50	30	9,000 sensors 9,000 sensors (multiregion) 3,000 sensors (single region) 900 sensors	448 103 34 13
Gather event information	Events	1,000	As needed. Events assumed to occur over 3-h morning and evening rush intervals.	1100 events reported over 24 h when raining	5.3
Send messages to roadside devices	Messages for changeable message signs	100	60	600 changeable message signs with 50% utilization at any one instant	4.4
Traffic adaptive signal control	Signal location, timing plan number, phase data	200	60	12,000 signals (multiregion) 6,000 signals (single region)	352 176
Transit route information	Transit route	Upload: 50 Download: 100,000	Infrequent	Static database	Negligible
Transit system information	Transit schedule adherence	50	60	3,000 stops with schedule deviations	22
Trip planning	Traveler information request	150	Infrequent	Static database	Negligible

[1] For the regions analyzed in reference [1]. Includes guard bands to separate 30-s and 60-s data packets and event information related to rain.

Source: *Communications Network High Level Design Document*, Draft, *Task 19* in *Southern California Priority Corridor Intermodal Transportation Management and Information System* (*SHOWCASE*) *High Level Design*, Iteris and NET, March 6, 2000.

Appendix C—Worksheets for Life-Cycle Cost and Risk Analysis Example

Table C-1. Decision tree worksheet for example of problem.

Decision Tree Worksheet		
CONFIGURATION	**PROB**	**LLCS OF BEST ACTION**
Configuration 1		
Major upgrade needed during life cycle	0.40	277.17
None	0.60	255.55
Average LLCs ($1000)	**264.20**	
Configuration 2		
Major upgrade needed during life cycle	0.10	287.64
None	0.90	279.81
Average LLCs ($1000)	**280.60**	
Configuration 3		
None	0.68	298.26
Technology obsolete	0.10	332.07
Major upgrade needed during life cycle	0.20	298.85
Technology obsolete and major upgrade	0.02	332.53
Average LLCs ($1000)	**302.44**	

Table C-2. LCCs worksheet for scenario 1-1.

Year (n)	Expenditure Item	Unit cost ($1000)	Unit	Subtotal (k) ($1000)	Discounting Rate (r%)	Present Value of Expenditure ($100) = $k \cdot \left[1 \Big/ \left(1 + \frac{r}{100}\right)^n \right]$
1	Equipment (Camera, spread spectrum radio or Microwave)	12.50	20	250.00	0.00	250.00
1	Labor	10.00	1	10.00	0.00	10.00
1	O&M	0.50	1	0.50	0.00	0.50
1	Training (engineer time)	0.05	100	5.00	0.00	5.00
2	O&M	0.50	1	0.50	2.00	0.48
3	O&M	0.50	1	0.50	2.00	0.47
3	Full Upgrade	30.00	1	30.00	3.20	27.29
4	O&M	1.00	1	1.00	2.00	0.92
5	O&M	1.00	1	1.00	2.00	0.91
6	O&M	1.00	1	1.00	2.00	0.89
7	O&M	2.00	1	2.00	2.00	1.74
8	O&M	2.00	1	2.00	2.00	1.71
8	Salvage Value	-20.00	1	-20.00	2.00	-17.07
LCCs	$282.84					

Table C-3. LCCs worksheet for scenario 1-2.

Year (n)	Expenditure Item	Unit cost ($1000)	Unit	Subtotal (k) ($1000)	Discounting Rate (r%)	Present Value of Expenditure ($100) = $k \cdot \left[1 \Big/ \left(1 + \frac{r}{100}\right)^n \right]$
1	Equipment (Camera, spread spectrum radio or Microwave)	12.50	20	250.00	0.00	250.00
1	Labor	10.00	1	10.00	0.00	10.00
1	O&M	0.50	1	0.50	0.00	0.50
1	Training (engineer time)	0.05	100	5.00	0.00	5.00
2	O&M	0.50	1	0.50	2.00	0.48
3	O&M	0.50	1	0.50	2.00	0.47
3	Partial Upgrade	5.00	1	5.00	3.20	4.55
4	O&M	1.00	1	1.00	2.00	0.92
5	O&M	1.00	1	1.00	2.00	0.91
6	O&M	1.00	1	1.00	2.00	0.89
7	O&M	2.00	1	2.00	2.00	1.74
8	O&M	2.00	1	2.00	2.00	1.71
8	Salvage Value	0.00	1	0.00	2.00	0.00
LCCs	$277.2					

Table C-4. LCCs worksheet for scenario 1-3.

Year (n)	Expenditure Item	Unit cost ($1000)	Unit	Subtotal (k) ($1000)	Discounting Rate (r%)	Present Value of Expenditure ($100) = $k \cdot \left[1 / \left(1 + \frac{r}{100}\right)^n \right]$
1	Equipment (Camera, spread spectrum radio or Microwave)	12.50	20	250.00	0.00	250.00
1	Labor	10.00	1	10.00	0.00	10.00
1	O&M	0.50	1	0.50	0.00	0.50
1	Training (engineer time)	0.05	100	5.00	0.00	5.00
2	O&M	0.50	1	0.50	2.00	0.48
3	O&M	0.50	1	0.50	2.00	0.47
4	O&M	1.00	1	1.00	2.00	0.92
5	O&M	1.00	1	1.00	2.00	0.91
6	O&M	1.00	1	1.00	2.00	0.89
7	O&M	2.00	1	2.00	2.00	1.74
8	O&M	2.00	1	2.00	2.00	1.71
8	Salvage Value	-1.00	20	-20.00	2.00	-17.07
LCCs	**$255.55**					

Table C-5. LCCs worksheet for scenario 2-1.

Year (n)	Expenditure Item	Unit cost ($1000)	Unit	Subtotal (k) ($1000)	Discounting Rate (r%)	Present Value of Expenditure ($100) = $k \cdot \left[1 / \left(1 + \frac{r}{100}\right)^n \right]$
1	Equipment (camera systems, 802.11x system, etc.)	10.00	20	200.00	0.00	200.00
1	Labor	10.00	1	10.00	0.00	10.00
1	ISDN service charge	0.50	20	10.00	0.00	10.00
1	O&M	0.50	1	0.50	0.00	0.50
1	Training (engineer time)	0.05	100	5.00	0.00	5.00
2	ISDN service charge	0.50	20	10.00	3.00	9.43
2	O&M	0.50	20	10.00	3.00	9.43
3	O&M	0.50	1	0.50	3.00	0.46
3	ISDN service charge	0.50	20	10.00	3.00	9.15
4	O&M	1.00	1	1.00	2.00	0.92
4	ISDN service charge	0.50	20	10.00	2.00	9.24
5	O&M	1.00	1	1.00	2.00	0.91
5	ISDN service charge	0.50	20	10.00	2.00	9.06
6	O&M	1.00	1	1.00	2.00	0.89
6	ISDN service charge	0.50	20	10.00	2.00	8.88
7	O&M	2.00	1	2.00	2.00	1.74
7	ISDN service charge	0.50	20	10.00	2.00	8.71
8	O&M	2.00	1	2.00	2.00	1.71
7	ISDN service charge	0.50	20	10.00	2.00	8.71
8	Salvage Value	-1.00	20	-20.00	2.00	-17.07
LCCs	**$287.64**					

Table C-6. LCCs worksheet for scenario 2-2.

Year (n)	Expenditure Item	Unit cost ($1000)	Unit	Subtotal (k) ($1000)	Discounting Rate (r%)	Present Value of Expenditure ($100) = $k \cdot \left[1 \big/ \left(1+\frac{r}{100}\right)^n\right]$
1	Equipment (camera systems, 802.11x system, etc.)	10.00	20	200.00	0.00	200.00
1	Labor	10.00	1	10.00	0.00	10.00
1	ISDN service charge	0.50	20	10.00	0.00	10.00
1	O&M	0.50	1	0.50	0.00	0.50
1	Training (engineer time)	0.05	100	5.00	0.00	5.00
2	ISDN service charge	0.50	20	10.00	3.00	9.43
2	O&M	0.50	20	10.00	3.00	9.43
3	O&M	0.50	1	0.50	3.00	0.46
3	ISDN service charge	0.50	20	10.00	3.00	9.15
4	O&M	1.00	1	1.00	2.00	0.92
4	Full upgrade	30.00	1	30.00	2.00	27.72
4	ISDN service charge	0.50	20	10.00	2.00	9.24
5	O&M	1.00	1	1.00	2.00	0.91
5	ISDN service charge	0.50	20	10.00	2.00	9.06
6	O&M	1.00	1	1.00	2.00	0.89
6	ISDN service charge	0.50	20	10.00	2.00	8.88
7	O&M	2.00	1	2.00	2.00	1.74
7	ISDN service charge	0.50	20	10.00	2.00	8.71
8	O&M	2.00	1	2.00	2.00	1.71
7	ISDN service charge	0.50	20	10.00	2.00	8.71
8	Salvage Value	-1.00	20	-20.00	2.00	-17.07
LCCs	**$315.36**					

Table C-7. LCCs worksheet for scenario 2-3.

Year (n)	Expenditure Item	Unit cost ($1000)	Unit	Subtotal (k) ($1000)	Discounting Rate (r%)	Present Value of Expenditure ($100) = $k \cdot \left[1 \big/ \left(1+\frac{r}{100}\right)^n\right]$
1	Equipment (camera systems, 802.11x system, etc.)	10.00	20	200.00	0.00	200.00
1	Labor	10.00	1	10.00	0.00	10.00
1	ISDN service charge	0.50	20	10.00	0.00	10.00
1	O&M	0.50	1	0.50	0.00	0.50
1	Training (engineer time)	0.05	100	5.00	0.00	5.00
2	ISDN service charge	0.50	20	10.00	3.00	9.43
2	O&M	0.50	20	10.00	3.00	9.43
3	O&M	0.50	1	0.50	3.00	0.46
3	ISDN service charge	0.50	20	10.00	3.00	9.15
4	O&M	1.00	1	1.00	2.00	0.92
4	Partial upgrade	10.00	1	10.00	2.00	9.24
4	ISDN service charge	0.50	20	10.00	2.00	9.24
5	O&M	1.00	1	1.00	2.00	0.91
5	ISDN service charge	0.50	20	10.00	2.00	9.06
6	O&M	1.00	1	1.00	2.00	0.89
6	ISDN service charge	0.50	20	10.00	2.00	8.88
7	O&M	2.00	1	2.00	2.00	1.74
7	ISDN service charge	0.50	20	10.00	2.00	8.71
8	O&M	2.00	1	2.00	2.00	1.71
7	ISDN service charge	0.50	20	10.00	2.00	8.71
8	Salvage Value	-2.00	20	-40.00	2.00	-34.14
LCCs	**$279.81**					

Table C-8. LCCs Worksheet for scenario 3-1.

Year (n)	Expenditure Item	Unit cost ($1000)	Unit	Subtotal (k) ($1000)	Discounting Rate (r%)	Present Value of Expenditure ($100) = $k \cdot \left[1 / (1 + \frac{r}{100})^n \right]$
1	Equipment (Camera system, GPRS modems, etc.)	9.00	20	180.00	0.00	180.00
1	Labor	10.00	1	10.00	0.00	10.00
1	GPRS service charge	0.96	20	19.20	0.00	19.20
1	O&M	0.50	1	0.50	0.00	0.50
1	Training (engineer time)	0.05	100	5.00	0.00	5.00
2	GPRS service charge	0.96	20	19.20	3.00	18.10
2	O&M	0.20	20	4.00	3.00	3.77
3	O&M	0.20	1	0.20	3.00	0.18
3	GPRS service charge	0.50	20	10.00	3.00	9.15
4	O&M	0.20	1	0.20	2.00	0.18
4	GPRS service charge	0.96	20	19.20	2.00	17.74
5	O&M	0.20	1	0.20	2.00	0.18
5	GPRS service charge	0.96	20	19.20	2.00	17.39
6	O&M	0.20	1	0.20	2.00	0.18
6	GPRS service charge	0.96	20	19.20	2.00	17.05
7	O&M	0.20	1	0.20	2.00	0.17
7	GPRS service charge	0.96	20	19.20	2.00	16.71
8	O&M	0.20	1	0.20	2.00	0.17
7	GPRS service charge	0.96	20	19.20	2.00	16.71
8	Salvage Value	-2.00	20	-40.00	2.00	-34.14
LCCs	**$298.26**					

Table C-9 LCCs Worksheet for Scenario 3-2.

Year (n)	Expenditure Item	Unit cost ($1000)	Unit	Subtotal (k) ($1000)	Discounting Rate (r%)	Present Value of Expenditure ($100) = $k \cdot \left[1 / (1 + \frac{r}{100})^n \right]$
1	Equipment (Camera system, GPRS modems, etc.)	9.00	20	180.00	0.00	180.00
1	Labor	10.00	1	10.00	0.00	10.00
1	GPRS service charge	0.96	20	19.20	0.00	19.20
1	O&M	0.50	1	0.50	0.00	0.50
1	Training (engineer time)	0.05	100	5.00	0.00	5.00
2	GPRS service charge	0.96	20	19.20	3.00	18.10
2	O&M	0.20	20	4.00	3.00	3.77
3	O&M	0.20	1	0.20	3.00	0.18
3	GPRS service charge	0.50	20	10.00	3.00	9.15
4	O&M	0.20	1	0.20	2.00	0.18
4	Partial upgrade	10.00	1	10.00	2.00	9.24
4	GPRS service charge	0.96	20	19.20	2.00	17.74
5	O&M	0.20	1	0.20	2.00	0.18
5	GPRS service charge	0.96	20	19.20	2.00	17.39
6	O&M	0.20	1	0.20	2.00	0.18
6	GPRS service charge	0.96	20	19.20	2.00	17.05
7	O&M	0.20	1	0.20	2.00	0.17
7	GPRS service charge	0.96	20	19.20	2.00	16.71
8	O&M	0.20	1	0.20	2.00	0.17
8	Full upgrade (technology obsolete)	2.00	20	40.00	2.00	34.14
8	GPRS service charge	0.96	20	19.20	2.00	16.39
8	Salvage Value	-2.00	20	-40.00	2.00	-34.14
LCCs	**$341.31**					

Table C–10. LCCs worksheet for scenario 3-3.

Year (n)	Expenditure Item	Unit cost ($1000)	Unit	Subtotal (k) ($1000)	Discounting Rate (r%)	Present Value of Expenditure ($100) = $k \cdot \left[1 \Big/ \left(1 + \frac{r}{100}\right)^{n} \right]$
1	Equipment (Camera system, GPRS modems, etc.)	9.00	20	180.00	0.00	180.00
1	Labor	10.00	1	10.00	0.00	10.00
1	GPRS service charge	0.96	20	19.20	0.00	19.20
1	O&M	0.50	1	0.50	0.00	0.50
1	Training (engineer time)	0.05	100	5.00	0.00	5.00
2	GPRS service charge	0.96	20	19.20	3.00	18.10
2	O&M	0.20	20	4.00	3.00	3.77
3	O&M	0.20	1	0.20	3.00	0.18
3	GPRS service charge	0.50	20	10.00	3.00	9.15
4	O&M	0.20	1	0.20	2.00	0.18
4	GPRS service charge	0.96	20	19.20	2.00	17.74
5	O&M	0.20	1	0.20	2.00	0.18
5	GPRS service charge	0.96	20	19.20	2.00	17.39
6	O&M	0.20	1	0.20	2.00	0.18
6	GPRS service charge	0.96	20	19.20	2.00	17.05
7	O&M	0.20	1	0.20	2.00	0.17
7	GPRS service charge	0.96	20	19.20	2.00	16.71
8	O&M	0.20	1	0.20	2.00	0.17
8	Partial upgrade (technology obsolete)	2.00	20	40.00	2.00	34.14
8	GPRS service charge	0.96	20	19.20	2.00	16.39
8	Salvage Value	-2.00	20	-40.00	2.00	-34.14
LCCs	**$332.07**					

Table C–11. LCCs worksheet for scenario 3-4.

Year (n)	Expenditure Item	Unit cost ($1000)	Unit	Subtotal (k) ($1000)	Discounting Rate (r%)	Present Value of Expenditure ($100) = $k \cdot \left[1 \Big/ \left(1 + \frac{r}{100}\right)^{n} \right]$
1	Equipment (Camera system, GPRS modems, etc.)	9.00	20	180.00	0.00	180.00
1	Labor	10.00	1	10.00	0.00	10.00
1	GPRS service charge	0.96	20	19.20	0.00	19.20
1	O&M	0.50	1	0.50	0.00	0.50
1	Training (engineer time)	0.05	100	5.00	0.00	5.00
2	GPRS service charge	0.96	20	19.20	3.00	18.10
2	O&M	0.20	20	4.00	3.00	3.77
3	O&M	0.20	1	0.20	3.00	0.18
3	GPRS service charge	0.50	20	10.00	3.00	9.15
4	O&M	0.20	1	0.20	2.00	0.18
4	Full upgrade	1.00	1	1.00	2.00	0.92
4	GPRS service charge	0.96	20	19.20	2.00	17.74
5	O&M	0.20	1	0.20	2.00	0.18
5	GPRS service charge	0.96	20	19.20	2.00	17.39
6	O&M	0.20	1	0.20	2.00	0.18
6	GPRS service charge	0.96	20	19.20	2.00	17.05
7	O&M	0.20	1	0.20	2.00	0.17
7	GPRS service charge	0.96	20	19.20	2.00	16.71
8	O&M	0.20	1	0.20	2.00	0.17
8	GPRS service charge	0.96	20	19.20	2.00	16.39
8	Salvage Value	-2.00	20	-40.00	2.00	-34.14
LCCs	**$298.85**					

Table C–12. LCCs worksheet for scenario 3-5.

Year (n)	Expenditure Item	Unit cost ($1000)	Unit	Subtotal (k) ($1000)	Discounting Rate (r%)	Present Value of Expenditure ($100) = $k \cdot \left[1 \big/ \left(1 + \frac{r}{100}\right)^n \right]$
1	Equipment (Camera system, GPRS modems, etc.)	9.00	20	180.00	0.00	180.00
1	Labor	10.00	1	10.00	0.00	10.00
1	GPRS service charge	0.96	20	19.20	0.00	19.20
1	O&M	0.50	1	0.50	0.00	0.50
1	Training (engineer time)	0.05	100	5.00	0.00	5.00
2	GPRS service charge	0.96	20	19.20	3.00	18.10
2	O&M	0.20	20	4.00	3.00	3.77
3	O&M	0.20	1	0.20	3.00	0.18
3	GPRS service charge	0.50	20	10.00	3.00	9.15
4	O&M	0.20	1	0.20	2.00	0.18
4	Partial upgrade	0.50	1	0.50	2.00	0.46
4	GPRS service charge	0.96	20	19.20	2.00	17.74
5	O&M	0.20	1	0.20	2.00	0.18
5	GPRS service charge	0.96	20	19.20	2.00	17.39
6	O&M	0.20	1	0.20	2.00	0.18
6	GPRS service charge	0.96	20	19.20	2.00	17.05
7	O&M	0.20	1	0.20	2.00	0.17
7	GPRS service charge	0.96	20	19.20	2.00	16.71
8	O&M	0.20	1	0.20	2.00	0.17
8	GPRS service charge	0.96	20	19.20	2.00	16.39
8	Salvage Value	-1.00	20	-20.00	2.00	-17.07
LCCs	$315.46					

Table C-13. LCCs worksheet for scenario 3-6.

Year (n)	Expenditure Item	Unit cost ($1000)	Unit	Subtotal (k) ($1000)	Discounting Rate (r%)	Present Value of Expenditure ($100) = $k \cdot \left[1 \big/ \left(1 + \frac{r}{100}\right)^n \right]$
1	Equipment (Camera system, GPRS modems, etc.)	9.00	20	180.00	0.00	180.00
1	Labor	10.00	1	10.00	0.00	10.00
1	GPRS service charge	0.96	20	19.20	0.00	19.20
1	O&M	0.50	1	0.50	0.00	0.50
1	Training (engineer time)	0.05	100	5.00	0.00	5.00
2	GPRS service charge	0.96	20	19.20	3.00	18.10
2	O&M	0.20	20	4.00	3.00	3.77
3	O&M	0.20	1	0.20	3.00	0.18
3	GPRS service charge	0.50	20	10.00	3.00	9.15
4	O&M	0.20	1	0.20	2.00	0.18
4	Partial upgrade	0.50	1	0.50	2.00	0.46
4	GPRS service charge	0.96	20	19.20	2.00	17.74
5	O&M	0.20	1	0.20	2.00	0.18
5	GPRS service charge	0.96	20	19.20	2.00	17.39
6	O&M	0.20	1	0.20	2.00	0.18
6	GPRS service charge	0.96	20	19.20	2.00	17.05
7	O&M	0.20	1	0.20	2.00	0.17
7	GPRS service charge	0.96	20	19.20	2.00	16.71
8	O&M	0.20	1	0.20	2.00	0.17
8	Full upgrade (technology obsolete)	2.00	20	40.00	2.00	34.14
8	GPRS service charge	0.96	20	19.20	2.00	16.39
8	Salvage Value	-2.00	20	-40.00	2.00	-34.14
LCCs	$332.53					

Table C-14. LCCs worksheet for scenario 3-7.

Year (n)	Expenditure Item	Unit cost ($1000)	Unit	Subtotal (k) ($1000)	Discounting Rate (r%)	Present Value of Expenditure ($100) = $k \cdot \left[1 \big/ \left(1 + \frac{r}{100}\right)^n\right]$
1	Equipment (Camera system, GPRS modems, etc.)	9.00	20	180.00	0.00	180.00
1	Labor	10.00	1	10.00	0.00	10.00
1	GPRS service charge	0.96	20	19.20	0.00	19.20
1	O&M	0.50	1	0.50	0.00	0.50
1	Training (engineer time)	0.05	100	5.00	0.00	5.00
2	GPRS service charge	0.96	20	19.20	3.00	18.10
2	O&M	0.20	20	4.00	3.00	3.77
3	O&M	0.20	1	0.20	3.00	0.18
3	GPRS service charge	0.50	20	10.00	3.00	9.15
4	O&M	0.20	1	0.20	2.00	0.18
4	Partial upgrade	0.50	1	0.50	2.00	0.46
4	GPRS service charge	0.96	20	19.20	2.00	17.74
5	O&M	0.20	1	0.20	2.00	0.18
5	GPRS service charge	0.96	20	19.20	2.00	17.39
6	O&M	0.20	1	0.20	2.00	0.18
6	GPRS service charge	0.96	20	19.20	2.00	17.05
7	O&M	0.20	1	0.20	2.00	0.17
7	GPRS service charge	0.96	20	19.20	2.00	16.71
8	O&M	0.20	1	0.20	2.00	0.17
8	Partial upgrade (technology obsolete)	1.00	20	20.00	2.00	17.07
8	GPRS service charge	0.96	20	19.20	2.00	16.39
8	Salvage Value	-1.00	20	-20.00	2.00	-17.07
LCCs	**$332.53**					

Appendix D—Knowledge Base Built in ITS Wireless Technology Acquisition Knowledge Management System

This section compiles the knowledge base that researchers built in the Knowledge Management System for this project (http://atrl.utep.edu/telecom). For more updated information, please logon to the website for this WBKMS.

D.1.Wireless Technology

D.1.1. Tutorials

1. Designing a Wireless WAN (Wide Area Network):
Gives a very basic understanding needed to design a Wireless Wide Area Networks. Some of the important factors that play an important role in designing a wireless WAN.
URL: http://www.wirelesswans.com/design.html

2. Wireless LANs *Dated*: March 10, 2003
This website has the following articles on wireless LAN and its implementation by Rick Gallaher:

- **Wireless LAN Technology and Network Implementation**

This article will explore basic wireless theory, existing differences in standards for wireless technology, wireless compatibility, security, and results of wireless tests for 802.11b.

- **Wireless LAN Antennas**

A wireless LAN does no good if it cannot cover its required distance. Wireless LANs operate on radio waves that are subject to the laws of propagation. Antenna design does make a difference in the performance of your network. Knowing the gain of an antenna is important; however, understanding the principles of propagation and transmission pattern is equally important.
URL: http://www.convergedigest.com/tutorials/

3. The ABC's of Wireless LAN *Dated*: December 2002
Choosing the right WLAN technology is an important factor in determining the overall return on investment. This paper provides a brief overview of products based on 802.11 protocols. 802.11 technologies are advancing very quickly, and products based on these protocols have different features and capabilities. This document gives an excellent basic understanding of 802.11 a/b/g technologies, specifications, benefits, security, and applications.
URL: http://www.netgear.com/pdf_docs/wireless_abgs.pdf

4. Data Networking Basics *Dated*: June 15-16, 2003
It is a very good tutorial presentation on data networking. This gives a brief description of OSI (Open Systems Interconnection) model, differences between voice and data networks, data network models, LAN/WAN characteristics, and TCP/IP.
URL: http://atrl.utep.edu/telecom/docs/Data_Networking_Basics.pdf

5. Telecommunication Reports

This website lists a few reports that address the current telecommunication issues, such as new telecommunications developments as they apply to Intelligent Transportation Systems (ITS). The various components of ITS user services, including roadside transponders, variable message signs, and traffic signals, rely upon communication linkages in order to transmit and receive data. These components communicate with each other through various mediums, such as wireless networks, fiber optics, radio signals, and wireline connections.

URL: http://www.path.berkeley.edu/itsdecision/serv_and_tech/Telecommunications/reports/telecom_reports.html

6. Cellular Digital Packet Data (CDPD)

It gives a basic understanding of CDPD, packet switching networks, CDPD network components, etc. Although CDPD is phasing out. It does not hurt to take a look of this overview.

URL: http://atrl.utep.edu/telecom/docs/cdpd.pdf

7. Direct Sequence vs. Frequency Hopping

A comparison of spread spectrum methods and performance is discussed in this article. The IEEE 802.11 specifications define standards for three unlicensed wireless methods. Two of these methods use radio waves and the third uses infrared light. As infrared is a limited technology that is only capable of transmitting relatively short distance vs. radio-based methods, in this document we will explore the two RF options, known as Direct Sequence Spread Spectrum (DSSS) and Frequency Hopping Spread Spectrum (FHSS). To analyze which technology is better suited for your application, it is important to understand the vast differences in the technologies and the performance they will provide.

URL: http://www.wavewireless.com/classroom/whitepapers/FHSSvDSSS.pdf

8. The Principles of Spread Spectrum Communications

In Code Division Multiple Access (CDMA) systems all users transmit in the same bandwidth simultaneously. Communication systems following this concept are ``spread spectrum systems.'' In this transmission technique, the frequency spectrum of a data-signal is spread using a code uncorrelated with that signal. As a result the bandwidth occupancy is much higher then required. The codes used for spreading have low cross-correlation values and are unique to every user. This is the reason that a receiver, which has knowledge about the code of the intended transmitter, is capable of selecting the desired signal. There exist different techniques to spread a signal: Direct-Sequence (DS), Frequency-Hopping (FH), Time-Hopping (TH) and Multi-Carrier CDMA. It is also possible to make use of combinations of them.

URL: http://cobalt.et.tudelft.nl/~glas/ssc/techn/techniques.html

9. Spread Spectrum Communications

Over the past decade, a new commercial market place has been emerging, called spread spectrum (or code-division multiple access [CDMA for short]). This field covers the art of secure communications that is now being exploited for commercial and industrial purposes. Spread spectrum uses wide band, noise like (pseudo-noise) signals. Since spread spectrum signals are noise like, they are hard to detect. Spread spectrum is also hard to intercept or demodulate making the secure. Further, spread spectrum transmissions are hard to jam (interfere with) then narrow band signals. Because of the above two properties, this form of telecommunications has been used by the military since its conception.

URL: http://murray.newcastle.edu.au/users/staff/eemf/ELEC351/SProjects/Morris/project.htm

10. Welcome to the World of CDMA

CDMA is a complex concept that can be viewed at many levels. We intend to offer explanations suitable for a broader audience, form non-technical to expert. Some of the chapters are: Introduction, Multiple Access Wireless communications, The CDMA revolution, principles of CDMA, and the air interface.

URL: http://www.cdg.org/technology/cdma_technology/a_ross/index.asp

11. Implementing CDMA Technology

This tutorial gives introduction to spread spectrum and different types of spread spectrum techniques. It lays more emphasis on implementing CDMA technology such as transmitting data, complex modulation, receiving data, demodulation, pilot codes and more.

URL: http://www.bee.net/mhendry/vrml/library/cdma/cdma.htm

12. The ABCs of Spread Spectrum

The author talks about the basics of spread spectrum and gives a general overview. This is more helpful in giving a good understanding of spread spectrum and what it does and its applications in digital communications.

URL: http://www.sss-mag.com/ss.html

D.1.2. Reports

1. Commercial Mobile Radio Systems Applications in Public Transit *Dated*: June 2003

This paper documents the first phase of a three-phase study that will examine the potential role of commercial mobile radio systems for public transit use. The purpose of this paper is to describe emerging commercial services that have the potential to either replace or significantly enhance transit land mobile radio systems. This study was prompted by some very important regulatory actions that have a direct impact on both existing land mobile radio systems and commercial mobile radio systems used by transit properties.

URL: http://www.mitretek.org/publications/its/MP2003V2_05.doc

2. Broadband Wireless, Integrated Services, and Their Applications to Intelligent Transportation Systems *Dated*: June 2000

This paper introduces some of the newer broadband wireless communications alternatives and describes how they could be used to provide high-speed connections between fixed, transportable, and mobile facilities. We also describe the new integrated service technologies—devices used to bundle voice, data, and video services for transmission over a single link. In this case, it's a broadband wireless link. Together, the new broadband wireless and integrated service technologies can be used to provide efficient, cost effective, and flexible multi-service provisioning. We introduce this concept and discuss its potential for Intelligent Transportation Systems (ITS).

URL: http://atrl.utep.edu/telecom/docs/broadbandwireless.pdf

3. Final Report: Mobile Surveillance and Wireless Communication Systems Field Operational Test Volume 1 *Dated*: March 1999

The Mobile Surveillance and Wireless Communication Systems Field Operational Test (FOT) evaluated the performance of wireless traffic detection and communications systems in areas where permanent detectors, electrical power, and landline communications were not available. The FOT partners designed and built six surveillance and three ramp meter trailers, a video and data retransmission or relay site, and video and data reception facilities at the Caltrans District 12 and

Anaheim Traffic Management Center (TMC) and the University of California at Irvine Institute of Transportation Studies (UCI-ITS) Laboratory. The system was evaluated in two different types of tests. The Anaheim Special Event Test assessed the surveillance trailers in an application that transmitted video imagery in support of arterial traffic control during a special event. The Interstate-5 (I-5) Test examined the use of the mobile surveillance and ramp meter trailers to transmit video imagery and data in support of freeway ramp metering. The primary tasks of the surveillance trailer are to acquire video imagery and traffic data, transmit metering rates to the ramp meter trailer, and transmit traffic flow data and imagery to the relay site. The major components of the surveillance trailer are a video image processor (VIP); two pan and tilt black-and-white cameras; one pan, tilt, and zoom color camera; one fixed black-and-white security camera; a 170 controller; wide and narrow bandwidth spread spectrum radios (SSRs) for video and data transmission; a telescoping 30-foot (9.1-meter) mast; a security system; and a propane-powered electrical generator and power supply system. The ramp meter trailer retransmits the metering rates to portable signal heads on the ramp and controls the meter-on sign. The major components of the ramp meter trailer are two traffic signal heads, a ramp meter-on sign, narrow band SSRs for data reception, and solar-powered electrical recharging systems for one signal head and the meter-on sign. The relay site on the Union Bank Building in Santa Ana, CA supports trailer locations along the I-5 reconstruction zone in Orange County, CA. Video imagery and data received at the relay site are retransmitted to the TMCs and to the UCI-ITS Laboratory. Three issues that affect the portability of the mobile surveillance and communications system became apparent. First, the size of the trailers limits where they can be placed in a construction zone. Second, since the configuration of a construction zone may change weekly or daily, the trailer is subject to frequent moves that are exacerbated by their size. Third, the current existence of only one relay site limits the areas in which the trailers can be deployed.
URL: http://atrl.utep.edu/telecom/docs/KleinFOTv1.pdf

4. **Final Report: Mobile Surveillance and Wireless Communication Systems Field Operational Test Volume 2** *Dated*: March, 1999

The Mobile Surveillance and Wireless Communication Systems Field Operational Test (FOT) evaluated the performance of wireless traffic detection and communications systems in areas where permanent detectors, electrical power, and landline communications were not available. The primary tasks of the surveillance trailer are to acquire video imagery and traffic data, transmit metering rates to the ramp meter trailer, and transmit traffic flow data and imagery to the relay site. The major components of the surveillance trailer are a video image processor (VIP); two pan and tilt black-and-white cameras; one pan, tilt, and zoom color camera; one fixed black-and-white security camera; a 170 controller; wide and narrow bandwidth spread spectrum radios (SSRs) for video and data transmission; a telescoping 30-foot (9.1-meter) mast; a security system; and a propane-powered electrical generator and power supply system. The ramp meter trailer retransmits the metering rates to portable signal heads on the ramp and controls the meter-on sign. The major components of the ramp meter trailer are two traffic signal heads, a ramp meter-on sign, narrow band SSRs for data reception, and solar-powered electrical recharging systems for one signal head and the meter-on sign. The relay site on the Union Bank Building in Santa Ana, CA supports trailer locations along the I-5 reconstruction zone in Orange County, CA. Video imagery and data received at the relay site are retransmitted to the TMCs and to the UCI-ITS Laboratory. Three issues that affect the portability of the mobile surveillance and communications system became apparent. First, the size of the trailers limits where they can be placed in a construction zone. Second, since the configuration of a construction zone may change weekly or daily, the trailer is subject to frequent moves that are exacerbated by their size. Third, the current existence of only one relay site limits the areas in which the trailers can be deployed. Sub grade placement is not possible because of line-of-sight restrictions.

Two recommendations based on these findings are that: (1) road construction contractors are made aware early in the planning process for the need to allocate sites for the surveillance, and perhaps ramp meter, trailers in the construction zones; (2) additional or supplemental relay sites be designed and deployed in areas from which Caltrans desires video and VIP data. The average percent differences between the permanent inductive loop detector (ILD) and VIP-measured mainline total volume and average lane occupancy were Đ22 and 8, respectively, based on data gathered in the fourteen runs completed in the I-5 Test. These accuracies appear adequate for the rush-hour ramp-metering application as shown by the tracking of the metering rates produced by the ILD and VIP data. These errors were tolerable because a more restrictive metering rate (namely zero) than the pre-stored time-of-day (TOD) rate was calculated by the metering algorithm from the ILD and VIP real-time data. Therefore, the algorithm reverted to the less restrictive TOD rate for both sets of data. The ramp signals responded properly to vehicle demand an average of 85 percent of the time. This is not good enough for ramp-metering operation. A possible method to increase this average is to position the surveillance trailer, and hence the camera, closer to the ramp. This may provide a better perspective of the vehicles on the ramp and perhaps modify the cameras field of view to allow even more VIP detection zones to be created upstream of the ramp stop bar. The multiple detection zones can then be connected with OR logic to increase the probability that a stopped vehicle will be detected by the VIP.
URL: http://www.itsdocs.fhwa.dot.gov/jpodocs/edlbrow/9_f01!.pdf

5. **Final Report: Mobile Surveillance and Wireless Communication Systems Field Operational Test Volume 3** *Dated*: March 1999

The Mobile Surveillance and Wireless Communication Systems Field Operational Test (FOT) evaluated the performance of wireless traffic detection and communications systems in areas where permanent detectors, electrical power, and landline communications were not available. The primary tasks of the surveillance trailer are to acquire video imagery and traffic data, transmit metering rates to the ramp meter trailer, and transmit traffic flow data and imagery to the relay site. The major components of the surveillance trailer are a video image processor (VIP); two pan and tilt black-and-white cameras; one pan, tilt, and zoom color camera; one fixed black-and-white security camera; a 170 controller; wide and narrow bandwidth spread spectrum radios (SSRs) for video and data transmission; a telescoping 30-foot (9.1-meter) mast; a security system; and a propane-powered electrical generator and power supply system. The ramp meter trailer retransmits the metering rates to portable signal heads on the ramp and controls the meter-on sign. The major components of the ramp meter trailer are two traffic signal heads, a ramp meter-on sign, narrow band SSRs for data reception, and solar-powered electrical recharging systems for one signal head and the meter-on sign. The relay site on the Union Bank Building in Santa Ana, CA supports trailer locations along the I-5 reconstruction zone in Orange County, CA. Video imagery and data received at the relay site are retransmitted to the TMCs and to the UCI-ITS Laboratory. Three issues that affect the portability of the mobile surveillance and communications system became apparent. First, the size of the trailers limits where they can be placed in a construction zone. Second, since the configuration of a construction zone may change weekly or daily, the trailer is subject to frequent moves that are exacerbated by their size. Third, the current existence of only one relay site limits the areas in which the trailers can be deployed. Sub grade placement is not possible because of line-of-sight restrictions. Two recommendations based on these findings are that: (1) road construction contractors are made aware early in the planning process for the need to allocate sites for the surveillance, and perhaps ramp meter, trailers in the construction zones; (2) additional or supplemental relay sites be designed and deployed in areas from which Caltrans desires video and VIP data. The average percent differences between the permanent inductive loop detector (ILD) and VIP-measured mainline total volume and average lane occupancy were Đ22 and 8, respectively, based on data gathered in the

fourteen runs completed in the I-5 Test. These accuracies appear adequate for the rush-hour ramp-metering application as shown by the tracking of the metering rates produced by the ILD and VIP data. These errors were tolerable because a more restrictive metering rate (namely zero) than the pre-stored time-of-day (TOD) rate was calculated by the metering algorithm from the ILD and VIP real-time data. Therefore, the algorithm reverted to the less restrictive TOD rate for both sets of data. The ramp signals responded properly to vehicle demand an average of 85 percent of the time. This is not good enough for ramp-metering operation. A possible method to increase this average is to position the surveillance trailer, and hence the camera, closer to the ramp. This may provide a better perspective of the vehicles on the ramp and perhaps modify the cameras field of view to allow even more VIP detection zones to be created upstream of the ramp stop bar. The multiple detection zones can then be connected with OR logic to increase the probability that a stopped vehicle will be detected by the VIP.
URL: http://www.itsdocs.fhwa.dot.gov/jpodocs/repts_te/@3101!.pdf

D.1.3. News

1. Third Generation Wireless *Dated*: November 25, 2002
Key features of the Third Generation Wireless systems from the Wireless Telecommunications Bureau website. Some of the proposed rules for Advanced Wireless Services in the 1.7 GHz and 2.1 GHz bands are also discussed here.
URL: http://www.fcc.gov/3G/

2. Intelligent Transportation Systems: Mirage or Reality?
This article discusses the need for intelligent transportation systems and the use of wireless communication technologies for ITS implementation. It mainly highlights the applications of intelligent transportation systems.
URL: http://stewks.ece.stevens-tech.edu/EE683/TechArticles/mwjournal/article12/ITS.html

3. High Data Rate Wireless Communications
This article highlights information regarding technologies for providing high data rate wireless communications by providing a limited communications industry survey, a comparison of the various connectivity technologies and possible means of expanding the data rate to allow more efficient communications connectivity.
URL: http://stewks.ece.stevens-tech.edu/EE683/TechArticles/mwjournal/article16/HiDataR.html

4. Wellink And Wi-LAN Collaborate on Development of Broadband Mobile Wireless Intelligent Transportation Systems Products *Dated*: April 1, 2003
Latest news on the collaboration of the two companies Wellink and WiLAN to develop W-OFDM products. ITS applications include real time video security, advertising, and Internet.
URL: http://www.bbwexchange.com/news/2003/apr/wilan040103.asp

5. "The Sky's the Limit: Spread Spectrum Radio Is Linking Traffic Networks from the Ground Up," by Jeremy Hiebert *Dated*: July 2003
The importance and late foray of spread spectrum technology and products into intelligent transportation related applications. A good analysis of the advantages of the Frequency Hopping Spread Spectrum techniques (FHSS) in ITS applications.
URL: http://www.itsa.org/mn.nsf/0/3388dc5ff3c681cc85256d6300763b4e?OpenDocument

6. Intel to Develop 802.16a Silicon for "Last Mile" Wireless Broadband Solutions *Dated*: July 9, 2003

Intel and Alvarion will work together to develop WiMAX-Certified products. Intel is going to develop IEEE 802.16a standard based product together with Alvarion. The network based on this standard will have a range of up to 30 miles and the ability to transfer data, voice, and video at speeds of up to 70 Mbps.

URL: http://www.intel.com/pressroom/archive/releases/20030709net.htm

7. IEEE Approves 802.11g Standard *Dated*: June 12, 2003

The standard board of IEEE has approved a new wireless LAN standard 802.11g that offers more carrying capacity than the current IEEE 802.11b specification. The new standard, 802.11g, lays out the ground rules for wireless LAN gear that is capable of at least 24 Mbps and up to 54 Mbps, while remaining backward compatible with existing 802.11b gear that runs at a maximum 11 Mbps. Both use radio spectrum in the range 2.4 GHz.

URL: http://www.infoworld.com/article/03/06/12/HNwifistandard_1.html

8. Dell to Offer GSM/GPRS Card for Notebooks *Dated*: June 24, 2003

Dell will offer its notebook customers the choice of WLAN (wireless LAN) or WWAN (wireless wide area network) technology under an agreement signed Tuesday with AT&T Wireless Services to let Dell customers connect to cellular data networks through an expansion card.

URL: http://www.infoworld.com/article/03/06/24/HNdellgsm_1.html

9. Verizon to Roll Out Push-to-Talk *Dated*: August 14, 2003

Verizon Wireless this week said it will turn up a nationwide "push-to-talk" service on Monday. It will become the only operator to offer walkie-talkie type service after Nextel. Push-to-talk allows customers to connect directly with other push-to-talk users on the same network by pressing a button on their handset.

URL: http://www.infoworld.com/article/03/08/14/HNtalkie_1.html

10. Technology Trend Predictions *Dated*: July 2003

As more communication bands are opened to high-speed wireless communications, more vendors are entering the wireless market. New products will solve the security issues. It is conceivable that all networks will be wireless in five to ten years. The next couple of years will see tremendous growth in similar technology.

URL: http://www.darwinmag.com/read/070103/wireless.html

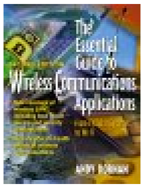
11. The "Sunsetting" of CDPD Technology Causes Transportation and Public Safety Agencies to Scramble *Dated*: June 15, 2003

The recent and perhaps inevitable decision by wireless communications firms such as AT&T Wireless and Verizon Wireless to cease supporting cellular digital packet data (CDPD) networks as soon as mid-2004 is causing ripples throughout the transportation and public safety communities, especially in larger metropolitan areas. Clearly, newer and faster wireless data communications technologies that are replacing CDPD will open the door to many new and more powerful ITS and security applications.

Url: http://www.nawgits.com/icdn/cdpd_demise.html

D.1.4. Books & Magazines

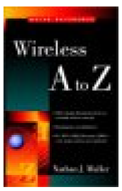
1. The Essential Guide to Wireless Communications Applications



Written for managers and sales professionals, this non-technical guide overviews the technology behind the most common forms of wireless communication, and explores their potential applications for the future. The second edition adds a chapter on the health risks associated with using cell phones, and sections on ultra-wideband, T- rays, and wireless LANs based on wireless Ethernet (Wi-Fi).

URL: http://www.amazon.com/exec/obidos/ASIN/0130097187/costeffective-20/104-9888533-0882349

2. Wireless A to Z



Network Essentials guides consist of 100 3-5 page articles, heavily illustrated, covering the basic concepts, technologies, standards and protocols – everything you need to master the field. Wireless A to Z covers the key concepts and technologies of wireless and mobile communications. From traditional topics like CDMA and signal hand-offs to cutting edge mobile applications like Wi-Fi and Bluetooth, this is a precise – and concise – quick look up reference to the industry.

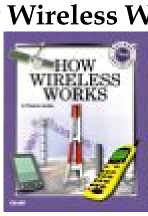
URL: http://www.amazon.com/exec/obidos/ASIN/0071410880/costeffective-20/104-9888533-0882349

3. Wireless Telecommunications FAQs

The wireless communications industry is growing rapidly. Newcomers and old-timers alike need help to catch up, and they will find it in this book: answers to the most frequently asked questions; new technologies and nomenclatures covered in detail; quick answers to key, specific questions; all of wireless, including RF and network issues. The tabbed interior design for easy lookup makes this the perfect desk reference.

URL: http://www.amazon.com/exec/obidos/ASIN/0071341021/costeffective-20/104-9888533-0882349

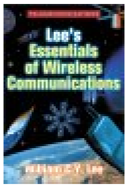
4. How Wireless Works



How Wireless Works continues in the How It Works series tradition by explaining every aspect of wireless communications, from the remote control on your coffee table to the most sophisticated wireless Internet networks. As wireless technology proliferates, readers will need to understand how wireless technologies work in order to make educated buying and business decisions related to wireless technologies. This book will provide readers with a basic technical background on wireless.

URL: http://www.amazon.com/exec/obidos/ASIN/0789724871/costeffective-20/104-9888533-0882349

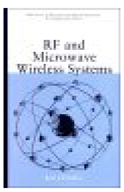
5. Lee's Essentials of Wireless Communications



If you have to navigate the dangerous waters of wireless, do it with a tech-savvy, predictive manual at your side. That's *Lee's Essentials of Wireless Communications,* written by the top-selling author in telecom, William C. Y. Lee. Smart wireless choices are not always obvious; a good deal of conventional wisdom is wrong. This expert guide helps you understand and compare CDM, SSB, CT-2, GSM, TDMA, IDEN (MIRS), LEO-Globalstar v. Iridium, IMT-2000, PCS, Wireless Local Loop (WLL), Wideband v. Narrowband, Analog Cellular, Digital Cellular, Radio Capacity, AMPS, ESS, Propagation System Strength Prediction, CDPD, UPR, and Two-Way Paging. Here's everything you need for making wireless decisions that work today (and will still work tomorrow) -- from insider data on coming user demands to the tools for writing glitch-free, foresighted technical specs.

URL: http://www.amazon.com/exec/obidos/ASIN/0071345426/costeffective-20/104-9888533-0882349

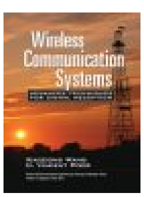
6. RF Microwave Wireless Systems



Explains all aspects of radio frequency (RF) and microwave wireless systems, including general hardware components, system parameters, and architectures. Covers both communication and radar/sensor systems and extends the discussion to other topics, such as global positioning systems and smart highways and smart cars. Reviews waves and transmission lines, examines modulation and demodulation and multiple- access techniques, and helps bridge the gap between RF/microwave engineering and communication system design.

URL: http://www.amazon.com/exec/obidos/ASIN/0471351997/costeffective-20/104-9888533-0882349

7. Wireless Communications Systems: Advanced Techniques for Signal Reception



The authors provide a unified description of methodologies for advanced receiver signal processing in wireless communications. It covers techniques for combating channel impairments and enhancing signal reception such as interference suppression and space-time processing.

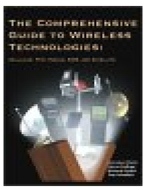
URL: http://www.amazon.com/exec/obidos/ASIN/0130214353/costeffective-20/104-9888533-0882349

8. **Wireless Communications: Principles and Practice (2nd Edition)**

This textbook on wireless communications technology and system design covers the basic issues affecting all wireless networks and reviews new technological developments, with particular attention to SG systems and wireless local area networks. Individual chapters concentrate on the cellular concept, mobile radio propagation, modulation techniques, multiple access techniques, and wireless systems and standards. Step-by-step explanations of practical examples illustrate major points.

URL: http://www.amazon.com/exec/obidos/ASIN/0130422320/costeffective-20/104-9888533-0882349

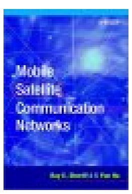
9. **The Comprehensive Guide to Wireless Technology**



This guide offers a comprehensive look at the wireless technologies available today. A welcome addition to our corporate library.

URL: http://www.amazon.com/exec/obidos/ASIN/0965065847/costeffective-20/104-9888533-0882349

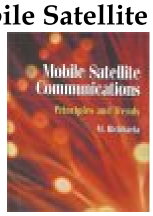
10. **Mobile Satellite Communication Networks**



Mobile satellite services are set to change with the imminent launch of satellite personal communication services (S-PCS), through the use of non-geostationary satellites. This new generation of satellites will be placed in low earth orbit or medium earth orbit, hence, introducing new satellite design concepts. One of the first texts to cover this rapidly evolving field, this text provides the reader with an overview of mobile satellite systems, from their initial introduction (Inmarsat),

URL: http://www.amazon.com/exec/obidos/ASIN/047172047X/costeffective-20/104-9888533-0882349

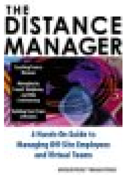
11. **Mobile Satellite Communications**



Demand for Mobile Satellite Services (MSS) is on the increase, with a huge surge in interest in the mobile communications market in recent years and high-pace changes and proliferation in the supporting system architectures and applications. This book provides a comprehensive guide to the current technologies and emerging trends of the future facing telecommunications professionals. It takes a system level approach, giving in-depth treatment of technical and business-related issues. The author, a leading expert in the area, draws on his extensive experience in industry and research, to provide you with a sound and informed understanding of the technology. Mobile Satellite Communications…

URL: http://www.amazon.com/exec/obidos/ASIN/020133142X/costeffective-20/104-9888533-0882349

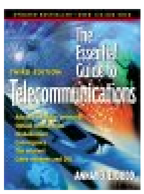
12. The Distance Manager: A Hands on Guide to Managing Off-Site Employees and Virtual Teams



Global business demands and new technologies have created a virtual workplace for many companies, with employees and teams routinely collaborating from distant geographical locations on the road, from home, at client sites--even on the other side of the globe. The Distance Manager provides practical information and tools to help managers bridge the communication gaps created by geographical separation, and get peak performance from employees they rarely see. This handbook is perfect for sales managers, project team leaders, senior managers, and anyone who manages people at more than one location. Key topics include: • Using e-mail, teleconferencing, and videoconferencing for maximum effectiveness • Mastering the people skills required to manage from a distance • Virtual team building, and strategies for managing multiple locations

URL: http://www.amazon.com/exec/obidos/ASIN/0071360654/costeffective-20/104-9888533-0882349

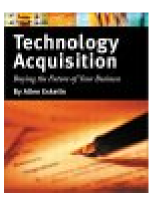
13. The Essential Guide to Telecommunications



The telecommunications industry encompasses hundreds of different technologies, which in turn have spawned many trade names, jargon terms, and legal definitions. Those looking for a comprehensive introduction to the technologies, laws, and marketing programs that govern telecommunications need to read *The Essential Guide to Telecommunications.*

URL: http://www.amazon.com/exec/obidos/ASIN/0130649074/costeffective-20/104-9888533-0882349

14. Technology Acquisition: Buying the Future of Your Business



Shows information technology, IP, managers when and how to obtain products from vendors, whom to buy from, and what to buy. Aims to help readers use limited resources to accomplish more, through the use of third parties. Goes step-by-step through the entire process, from initiation to managing ongoing operations.

Url: http://www.amazon.com/exec/obidos/ASIN/020173804X/costeffective-20/104-9888533-0882349

15. Network World Fusion

This is an online magazine with daily news, vendor news in the networking world. It also has plenty of white papers on wireless communication technologies. The research center has a number of articles analyzing the existing wireless technologies and the latest developments in the wireless industry.

URL: http://www.nwfusion.com/index.html

16. Wireless Week

This online magazine has latest news from the wireless industry, with subscription issues and newsletters. It includes webcasts, old archives, industry research, etc.

URL: http://www.wirelessweek.com/

17. Wireless Systems Design

Wireless systems design is a magazine for designers of communications and computer systems. It is presented by Penton Electronics Group. It has forums, an interface with other professionals in the communications and computer-system-design industry or discussion topics featured in *Wireless Systems Design.*

URL: http://www.wsdmag.com/Index.html?Ad=1

18. Wireless Newsfactor

A news website, with up-to-date developments in the wireless industry. It has articles on 3G wireless, wireless web, satellite, etc.

URL: http://www.wirelessnewsfactor.com/

19. Wireless Design Online

It is an online wireless resource magazine with white papers and free newsletters. Including wireless training, discussion forums, also sells and buys market research reports.

URL: http://www.wirelessdesignonline.com/

20. Wireless Design & Development

This is the designer's source for wireless technology with weekly free newsletters.

URL: http://www.wirelessdesignmag.com/scripts/default.asp

21. Spread Spectrum Scene Online

Spread Spectrum Online is a RF, wireless, and spread spectrum resource. This website is sponsored by Pegasus Technologies, a RF/Wireless design consultants.

URL: http://www.sss-mag.com/

22. RCR Wireless News

This is a wireless news magazine.

URL: http://www.rcrnews.com/

23. RadioResource Magazine

Mission Critical Communications (formerly *RadioResource Magazine*), Public Safety Report, and RadioResource International deliver wireless voice and data solutions for mobile, remote and mission-critical operations. We provide the information you need to improve your organization's operations through the efficient use of wireless communications.

URL: http://www.radioresourcemag.com/

24. Microwave Engineering Online

Microwave Engineering is an online resource for microwave related news, suppliers, events, workshops, etc.

URL: http://www.mwee.com/

25. Microwaves & RF Magazine
Latest news and developments related to microwave and RF, with up-to-date searchable database of products, manufacturers, and sales offices.
URL: http://www.mwrf.com/

26. Comms Design
This is a resourceful website for design issues on Broadband design, 2.5G/3G wireless, Optical networking, etc.
URL: http://www.commsdesign.com/

27. Communications Engineering & Design
This is a premier magazine for broadband technology.
URL: http://www.cedmagazine.com/

28. Broadband Wireless Online
Broadband wireless online has latest news on broadband wireless, features, interviews, subscription to their weekly newsletters, Upcoming industry events, wireless glossary, etc. This is sponsored by Shorecliff Communications LCC.
URL: http://www.shorecliffcommunications.com/magazine/

29. Wireless & Mobile Technology
Features latest news and developments in the field of wireless.
URL: http://www.eweek.com/category2/0,4148,1237892,00.asp

D.1.5. Glossary

1. Acronym Guide to RF Wireless & Digital Communication Terms from Newwave Instruments
New Wave Instruments maintains a comprehensive directory of exceptional spread spectrum resources, ranging from tutorials, theory, and circuit diagrams, to development tools, OEM products, and spread spectrum consultants. This link provides general wireless terms that are often associated with spread spectrum technology.
Url: http://www.newwaveinstruments.com/resources/digital_communication_terms.htm#Digital

2. Mobile World
Mobile World provides a glossary for all the wireless technical terms.
URL: http://www.mobileworld.org/glossary.html

3. Glossary of Communication Terms from TIA B2B
Source: Federal Standard 1037C - August 7, 1996: Glossary of Telecommunication Terms. The contents of this glossary have been updated and expanded by Technical Committee T1. The revised glossary has been published as American National Standard T1.523-2001.
URL: http://www.tiab2b.com/glossary/

4. Wireless Dictionary from Agilent Technologies
This website has a downloadable wireless dictionary.
URL: http://www.agilent.com/cm/wireless/dictionary/a.html

5. Spread Spectrum & CDMA Technology Glossary
If you've ever wondered, "what is multipath fading," or "what does W-CDMA stand for," or "CDMA vs. TDMA," you've come to the right place. The description or definition of most every spread spectrum term and phrase can be found here, in New Wave Instruments spread spectrum dictionary.
URL: http://www.newwaveinstruments.com/resources/glossary.htm - Spread Spectrum Glossary

D.2. Technology Project Management

D.2.1. Tutorials

1. Mobile Radio System Cost D*ated*: March 1, 2002
A simple case study on calculating costs between commercial and private radio systems for public safety agencies.
URL: http://iwce-mrt.com/ar/radio_not_question_money/index.htm

2. Transportation Research for the Age of Wireless Telecommunications *Dated*: October 2001
A very good presentation made by Professor Hani S. Mahmassani at University of Maryland at College Park. The presentation involves, Challenges in transportation-Telecommunication interactions, and application of information and telecommunication technologies to improve the operational performance of transportation systems and facilities.
URL: http://atrl.utep.edu/telecom/docs/mahmassani.pdf

3. Present Value Analysis for Selecting a Communication Medium for a Traffic Signal Control System in Richardson, Texas
Due to rapidly evolving technology in the telecommunications industry, many alternatives exist for a communications sub-system for traffic signal control. Traffic signal systems have a 10-12 year life due to an accelerated depreciation in a harsh operating environment and rapid advances in technology. The following alternatives are compared based on an initial capital investment and the net present value of maintenance costs and service fees projected over a 10-year life.

- Upgrade CATV Modems
- Telephone Lines and Modems
- Cellular Telephone Modems
- Mobile data networks
- Spread Spectrum radio

URL: http://atrl.utep.edu/telecom/docs/npv.pdf

4. Understanding Wireless Communication in Public Safety *Dated*: January 2003
A Guidebook to Technology, Issues, Planning, and Management by: Kathy J. Imel and James W. Hart, P.E. Additional material for the second edition contributed by John Powell, Tom Tolman, and David Funk For The National Law Enforcement and Corrections Technology Center (Rocky Mountain Region) A Program of the National Institute of Justice --Thanks to Richard Cortez (ELP).
This guidebook is divided into four parts:

Part 1: Planning and Managing a Communications Project: Discusses the overall scope of a project, including planning, funding, procurement, and management.

Part 2: Wireless Communications Technology: Discusses voice versus data, characteristics of radio systems (including terminology), and current types of public safety radio systems.

Part 3: Wireless Communications Issues: Discusses Federal Communications Commission (FCC) licensing, rules, regulations, and related issues; tower sitting and radio frequency radiation exposure; various Federal and other group initiatives; and interoperability.

Part 4: Wireless Communications Options: Discusses voice system options, data system options, and some of the latest developments in communications technology.

URL: http://atrl.utep.edu/telecom/docs/wireless2003.pdf

5. Telecommunication Reports

This website lists a few reports that address the current telecommunication issues, such as new telecommunications developments as they apply to Intelligent Transportation Systems (ITS). The various components of ITS user services, including roadside transponders, variable message signs, and traffic signals, rely upon communication linkages in order to transmit and receive data. These components communicate with each other through various mediums, such as wireless networks, fiber optics, radio signals, and wireline connections.

URL: http://www.path.berkeley.edu/itsdecision/serv_and_tech/Telecommunicatio ns/reports/telecom_reports.html

D.2.2. Reports

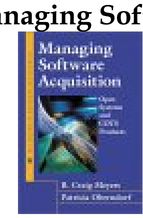
1. Functional Specification: Southern California Priority Corridor Intermodal Transportation Management and Information System (SHOWCASE) High Level Design *Dated*: June 02, 2000

This document defines the functional requirements and design for Version 1.0 of the Showcase Kernel. Showcase consists of a network that connects transportation centers and the Kernel, a collection of services that will allow transportation centers to communicate with each other and interoperate seamlessly. Showcase is being designed and developed in Phases. Phase I established the scope of Showcase and identified a series of "Early Start" transportation centers that will be connected by Showcase. Phase II established the functionality and basic high level design of Showcase, based on the user requirements developed with the seven identified Early Start projects. This design effort culminated in the development and demonstration of an initial prototype. Phase III, the current phase, refines the Phase II design and implementation based on additional user requirements and feedback from demonstration and tests of the Phase II prototype. Phase III will also implement functions deferred in Phase II. Figure 1 identifies the key documents governing the design and implementation of Phases II & III of Showcase. Showcase is being developed using a distributed object-oriented approach that will encourage development beyond Phase III as needs emerge and supporting technology becomes available.

URL: http://atrl.utep.edu/telecom/docs/showcase.pdf

D.2.3. Books

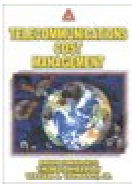
1. Managing Software Acquisition: Open Systems and COTS Products



In a book derived from courses they taught at the Carnegie Mellon Software Engineering Institute (SEI), Craig and Oberndorf discuss their seven element approach for project management staff to get started with commercial off-the-shelf (COTS) products, reference models and architectures, managing the transition, and an acquisition framework and models. Includes "food for thought" questions, sample questions for evaluating organizational needs, a glossary, acronym list, supporting tables and illustrations, and references

URL: http://www.amazon.com/exec/obidos/ASIN/0201704544/costeffective-20/104-9888533-0882349

2. Telecommunications Cost Management



Most telecom books focus on either traditional telecom billing audits or pure technology, with the cost saving ideas buried deep in the text. Busy decision-makers need the specifics quickly, without having to plow through details that do not affect the economics of a project. *Telecommunications Cost Management* takes cost saving techniques and brings them to the forefront where managers and decision makers can quickly use them for real world cost reductions or efficiency gains…

URL: http://www.amazon.com/exec/obidos/ASIN/0849311012/costeffective-20/104-9888533-0882349

3. Breakthrough Technology Project Management, 2e

Although there are many books of methods and tools in different areas, few books actually give detailed tips and lessons on how to effectively set up and manage projects. Most books on project management devote all their space to specific methods. *Breakthrough Technology Project Management,* Second Edition provides tangible guidelines through examples and suggestions to help people participate in and manage projects more effectively. The authors' techniques and guidelines have been proven over the past 15 years in courses and counseling. This book will prove a valuable tool for those working in information systems, engineering, computer science, operations and production, and other environments involving project management.

URL: http://www.amazon.com/exec/obidos/ASIN/0124499686/costeffective-20/104-9888533-0882349

4. Sys Admin Magazine

Sys Admin—the only magazine devoted 100% to UNIX systems administration—solid, technical information full of ways to improve the performance and extend the capabilities of your system. Regular columns and departments feature important books, new product releases and upgrades, career opportunities, and technical meetings and conferences. Coverage spans a variety of platforms including Solaris, AIX, HP-UX, SCO, Linux, and others.

URL: http://www.amazon.com/exec/obidos/ASIN/B000060MI8/costeffective-20/104-9888533-0882349

5. **PC World Magazine**

PC World is the best source of information on how to select, buy, and use computer products and services for home and business. It's packed with award-winning articles, monthly Top 100 PC and product rankings, evaluations and ratings from the PC World Test Center, tips, how-tos, consumer advice, step-by-step guides, and more.

URL: http://www.amazon.com/exec/obidos/ASIN/B00005N7S5/costeffective-20/104-9888533-0882349

6. **Computer Shopper Magazine**

This magazine is a source of information about direct sellers of computer products for committed mail order buyers.

URL: http://www.amazon.com/exec/obidos/ASIN/B00005N7PF/costeffective-20/104-9888533-0882349

7. **PC Magazine**

This magazine is designed for buyers of PC software, peripherals and accessories. It is written to provide the information needed to identify brands of PC related products and help make those products more useful in business. Its features include extensive product reviews based on tests, productivity enhancement departments and opinion/analysis columns.

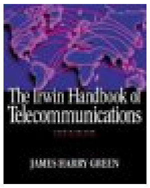
URL: http://www.amazon.com/exec/obidos/ASIN/B00005N7S4/costeffective-20/104-9888533-0882349

8. **Process Improvement and Organizational Learning: The Role of Collaboration Technologies**

This book analyzes the relationship between collaborative technologies, process improvement and organizational learning. It is based on the author's experiences in numerous process-focused organizational development projects and a three-year project where over 38 process improvement groups were aided by the support of collaborative technologies. This book will help managers prepare their organizations to survive and thrive in the information era. Only the fittest organizations will master the art of efficient and effective acquisition and the use of data, information and knowledge.

URL: http://www.amazon.com/exec/obidos/ASIN/1878289586/costeffective-20/104-9888533-0882349

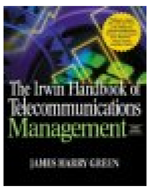
9. The Irwin Handbook of Telecommunications



What are the latest developments in telecommunications? How are new and emerging products impacting the industry and your job? Where are we headed tomorrow? *The Irwin Handbook of Telecommunications,* Fourth Edition provides the answers to virtually every question on the past, present and future of telecommunications. This covers-every-issue volume is the indispensable reference in the field, including detailed -- yet easy-to-understand -- coverage of:

URL: http://www.amazon.com/exec/obidos/ASIN/0071355545/costeffective-20/104-9888533-0882349

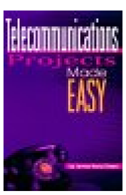
10. The Irwin Handbook of Telecommunications Management



Information and Solutions for Today's Telecommunications Systems. Regardless of your industry, you'll find James Harry Green's *The Irwin Handbook of Telecommunications Management,* Third Edition an authoritative how-to solutions manual for every telecommunications management question. Now comprehensively revised and updated, this classic resource provides hands-on techniques for understanding today's major technological changes -- and incorporating them into your organization's telecom strategy. Covering the entire spectrum of 21st century telecommunications, the Handbook makes it easy to locate, understand, and implement:

URL: http://www.amazon.com/exec/obidos/ASIN/0071370587/costeffective-20/104-9888533-0882349

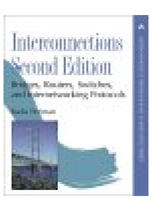
11. Telecommunications Projects Made Easy



This book and its disk bring order to complex telecommunications projects in two ways. First, it has a checklist of all the elements of common telecommunications projects. Second, the floppy disk contains comprehensive templates, which can be dropped in project management systems compatible with Microsoft Project 4.1. There are 18 projects covered on the floppy disk- ACD, Cable, Call Accounting, Conduit, Computer Telephone Integration, Data WAN, Equipment Room, Fiber, Hub, IVR, LAN, PBX, Remote Access Device, Router, Switch, Voice Mail, Voice WAN (Long Distance Network) and Wiring.

URL: http://www.amazon.com/exec/obidos/ASIN/1578200091/costeffective-20/104-9888533-0882349

12. Interconnections: Bridges, Routers, Switches, and Interworking Protocols (2nd Edition)



This latest release of Interconnections is a competent update of a networking classic. Radia Perlman explains hundreds of details about getting computers--and computer networks--to talk to one another smoothly, accurately, and efficiently. Perlman, inventor of the spanning-tree bridging algorithm, covers the Open Systems Interconnect (OSI) reference model, bridges, switches, hubs, Virtual Local Area Networks (VLANs), plus connection-based and connectionless network.

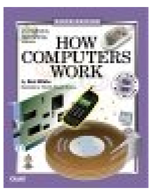
URL: http://www.amazon.com/exec/obidos/ASIN/0201634481/costeffective-20/104-9888533-0882349

13. Linux Hardware Handbook

Linux Hardware Handbook shows you how to make purchasing and installation decisions concerning hardware for Linux computers. Don't wade through scattered documentation to determine what products work and what products don't--this book provides general guidance and information on what will help you and what to avoid. This book helps you gain a greater understanding of the issues surrounding Linux and make more informed purchase decisions. Get the knowledge you need to decide whether to even...

URL: http://www.amazon.com/exec/obidos/ASIN/0672319187/costeffective-20/104-9888533-0882349

14. How Computers Work



Updated to include all the recent developments to the PC and complete with a CD-ROM, the third edition of *How Computers Work* is like a cool science museum in a book. But make no mistake--this is not a book for children. How Computers Work aims to teach readers about all the intricacies held within the machine, and it's a daunting task. The author, Ron White, doesn't dumb down his material; instead he provides thorough and substantive definitions. The pages of fun and colorful graphics ease the tension, though, and bring the abstract concepts—the difference between RAM and ROM, for example—into real life.

URL: http://www.amazon.com/exec/obidos/ASIN/0789725495/costeffective-20/104-9888533-0882349

15. Upgrading And Repairing PCs

This is the newest comprehensive update to the world's #1 guide to PC repair and maintenance. World renowned PC hardware expert Scott Mueller has thoroughly updated his legendary *Upgrading and Repairing PCs* to reflect today's latest PC technologies, and added a new DVD with more than two hours of digital video demonstrating PC maintenance and repair, which can be watched on either their DVD equipped PCs or any DVD player. Mueller presents updated coverage of every significant PC component…

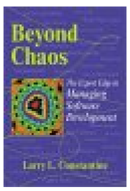
URL: http://www.amazon.com/exec/obidos/ASIN/0789727455/costeffective-20/104-9888533-0882349

16. Architecture-Centric Software Project Management

Many software luminaries believe that architecture is the most crucial element to success in software development. This text links software architecture and project management, providing practical techniques that speed time to market, improve performance, and reduce risk.

URL: http://www.amazon.com/exec/obidos/ASIN/0201734095/costeffective-20/104-9888533-0882349

17. Beyond Chaos: The Expert Edge in Managing Software Development



In *Beyond Chaos,* the keenest contributions to the Management Forum have been incorporated into a single volume to reveal best practices in managing software projects and organizations. The forty-five essays contained in this book are written by many of the leading names in software development, software engineering, and technical management. Each piece has been selected and edited to provide highly focused ideas and suggestions that can be translated into immediate practice. Pragmatic and provocative, they address key management concerns involving people, planning and productivity…

URL: http://www.amazon.com/exec/obidos/ASIN/0201719606/costeffective-20/104-9888533-0882349

18. Leading a Software Development Team

A complete guide to becoming an effective team leader in a software project development team. Covers questions often asked by those in leadership positions, offering practical tips and techniques on how to lead others and how to make good decisions and get the project out on time.

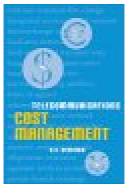
URL: http://www.amazon.com/exec/obidos/ASIN/0201675269/costeffective-20/104-9888533-0882349

19. Successful IT Project Delivery

This book sets out to address the causes of IT project failure and provides the reader with an opportunity so often denied within their own workplace—to learn the lessons from project failure. It uses private and public sector case studies to show how projects can fail easily if only a small number of critical success factors are not met.

URL: http://www.amazon.com/exec/obidos/ASIN/0201756064/costeffective-20/104-9888533-0882349

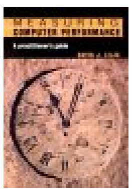
20. Telecommunications Cost Management (Artech House Telecommunications Library)



Here's a practical cost management guide to the complex world of voice, data and wireless telecommunications for the non-technical business professional. Examining the complex, highly technical telecommunications industry from an insider's point of view, it sifts through all the technical jargon, offers a comprehensive education on the applications, services and procurement of telecom products, and provides a strategy to effectively manage the costs of those products…

URL: http://www.amazon.com/exec/obidos/ASIN/1580531784/costeffective-20/104-9888533-0882349

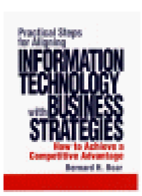
21. Measuring Computer Performance: A Practitioner's Guide



Measuring Computer Performance sets out the fundamental techniques used in analyzing and understanding the performance of computer systems. The emphasis is on practical methods of measurement, simulation, and analytical modeling. David Lilja discusses performance metrics and provides detailed coverage of the strategies used in benchmark programs. In addition to intuitive explanations of key statistical tools, he describes the general "design of experiments" technique and shows how the maximum amount of information can be obtained with minimum effort. Features include appendices listing common probability distributions and statistical tables and a glossary of important technical terms.

URL: http://www.amazon.com/exec/obidos/ASIN/0521641055/costeffective-20/104-9888533-0882349

22. Practical Steps for Aligning Information Technology with Business Strategies: How to Achieve a Competitive Advantage



Offering advice on how to improve and re-engineer any Information Technology (IT) organization, this practical book comes complete with charts and templates that an IS staff can easily customize and use immediately. This book discusses all the "hot" topics affecting IS today, including TQM, imaging, downsizing, client/server, and more.

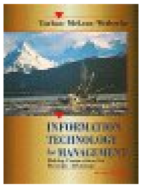
URL: http://www.amazon.com/exec/obidos/ASIN/0471076376/costeffective-20/104-9888533-0882349

23. Building Operational Excellence: Strategies to Improve IT People and Processes

Provides valuable insight for organizing IT people and processes, showing you how to improve end-to-end management of critical resources. Guides you through techniques of analysis, assessment, and change management that help create the center of excellence.

URL: http://www.amazon.com/exec/obidos/ASIN/0201767376/costeffective-20/104-9888533-0882349

24. Information Technology for Management: Making Connections for Strategic Advantage



A practical, managerial-oriented approach to getting the most out of IT. Managers will learn the most effective ways to use information systems in this new edition. The authors examine case studies to highlight new technology and applications including fuzzy logic, neural computing, and hypermedia.

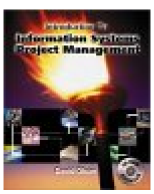
URL: http://www.amazon.com/exec/obidos/ASIN/0471178985/costeffective-20/104-9888533-0882349

25. A Practical Guide to Information Systems Strategic Planning

Today's technological advances are directly affecting the success of business tomorrow. With recent—and continual—improvements in technology, many organizations are finding their information systems obsolete, and are having to take a close look at their current Information Systems and answer some tough questions, including: How well are our current Information Systems applications meeting the business needs today? How well can they meet the needs of our business tomorrow?

URL: http://www.amazon.com/exec/obidos/ASIN/1574441337/costeffective-20/104-9888533-0882349

26. Introduction to Information System Project Management



This text is a project management text that focuses on "high technology." The text is brief and has more applied vs. theoretical coverage. The text will focus on traditional project management topics, i.e., project adoption, planning, scheduling, and implementation, however, Olson will look at these topics from an IS or software perspective.

URL: http://www.amazon.com/exec/obidos/ASIN/0072424206/costeffective-20/104-9888533-0882349

27. A Practical Guide to Information Systems Process Improvement

When you invest in expensive technology and systems, you want to get the most out of them. Process improvement has been used for years as an effective strategy to reduce costs, shorten cycle times, improve quality, and increase user satisfaction in other areas of business such as Quality, Manufacturing, and Engineering. While there are many books available on process improvement and process re-engineering, few of them address the unique processes within information systems as clearly and….

URL: http://www.amazon.com/exec/obidos/ASIN/1574442813/costeffective-20/104-9888533-0882349

Appendix E—Wireless Equipment and Wireless Data Service Vendors Registered in the Knowledge Management System Website

This section compiles a partial list of wireless communication vendors/contractors registered in the Knowledge Management System/web clearinghouse for this project http://atrl.utep.edu/telecom.

Company Name	Company's Self Introduction	Company Service	URL
ACEx Technologies, Inc.	Since 1979 ACEx has provided engineering design and implementation expertise to public agencies and private corporations. Our clients include transit and railroad agencies throughout the United States, federal and regional electrical power utilities, as well as major domestic system integrators. We have built our reputation and our company on the quality and responsiveness of our work, and the ability of our staff to work well with our clients.	We design and help implement communications networks and control systems for voice, video and data communications applications. Communications technologies include wide area and local area optical fiber networks, voice and data radio, and specialized technologies such as power-line communications.	www.acex.com
Advance Network Systems Inc.			www.anstyler.com
Advanced Wireless Solutions	AWS Inc. was founded in May of 2002 and began providing high-speed wireless Internet access to South Austin Business and South Rural Texas in September 11, 2002 they are headquartered in Austin Texas, and have grown into a complete Internet Access Provider including Inter office wireless networking performing quality installations and services.	Our engineers and installation technicians are highly trained and take responsibility of your network project from the Design phase to Premise Wiring, Hardware Installation, Testing, Network Monitoring, Tuning and Management. We install, terminate, and test: Voice and Data cable; Category 5/5e Cable; Coaxial Cable; Cable Runway / Routing Systems. We install: Wireless Networking Equipment, Cabinets, Equipment Racks Install Telecom Equipment	www.awsolutions.net
AeroComm Inc.	AeroComm is the worldwide leader in providing Instant Wireless data communications to original equipment manufacturers. Our company commands the industry with consistent breakthroughs, such as superior RF price and performance for both industrial and commercial applications.	AeroComm designs, manufactures and markets spread spectrum data radios for OEM integration or commercial plug-and-play.	www.aerocomm.com/index.htm
AirWaves	Established 1980-Two way radio sales, service,	Two-way radio installation & repair, paging service	

Company Name	Company's Self Introduction	Company Service	URL
Communications, Inc.	paging, towers. A Motorola Two-Way, Radius, Professional Conventional & Trunking dealer. Kenwood, Relm, E F Johnson, Maxon dealer.	statewide & beyond, Logic Trunked Radio systems, Tower space rental, Community repeater service.	
Alamon Telco, Inc.	Alamon Telco is a Women owned business that is certified by the Women's Business National Council as well as the North Central Texas Regional Certification Agency. Alamon has over 28 years experience in Telecommunications services. We are a tier one Vendor for many of the nation's largest manufacturers and operating companies.	Alamon Telco, Inc. Provides voice and data cabling services for cat5e, cat6 as well as fiber and coax. We provide wireless installations as well.	www.alamon.com
Andrew Corporation	Andrew Corporation is a global supplier of communications products and systems to worldwide commercial, industrial and governmental customers.	Andrew's principal products include coaxial cables, connectors, cable assemblies and accessories, power amplifiers, microwave antennas and products for point-to-point communication systems, television broadcasting antennas, special-purpose antennas for commercial and government use, antennas and earth stations for satellite communication systems, cellular antenna products, global positioning system (GPS) antennas and products, radar system components and related ancillary items and services. Sales, installation, turn-key, operation and maintenance.	www.andrew.com
Andrew Corporation	Andrew Corporation is a global supplier of communications products and systems to worldwide commercial, industrial and governmental customers.	Andrew's principal products include coaxial cables, connectors, cable assemblies and accessories, power amplifiers, microwave antennas and products for point-to-point communication systems, television broadcasting antennas, special-purpose antennas for commercial and government use, antennas and earth stations for satellite communication systems, cellular antenna products, global positioning system (GPS) antennas and products, radar system components and related ancillary items and services.	www.andrew.com
AnyWARE, Inc.	AnyWARE, Inc. is a networking company offering data and voice products from AT&T, Cisco, and other major vendors. We are an AT&T Alliance Partner, authorized to sell AT&T business communications services.	AnyWARE, Inc. offers a combination of professional services, including project management, engineering, installation, and account management. We provide products to businesses as well as state and local governments.	www.anywareinc.com

Company Name	Company's Self Introduction	Company Service	URL
ATE Telecom Solutions	Small business dedicated to integrate solutions in networks, including copper, fiber optic and wireless networks.	Installs copper, fiber, networking equipment. Satellite internet connection.	www.ate-tele.com
ATS-Plus, Inc.	ATS+ is a premier distributor for Ascom® Wireless Solutions, a market leading developer of workplace wireless communication solutions.	Using Ascom's products and solutions, ATS+ provides in-building wireless communication systems that are unique, durable and innovative.	www.atsplus.com
Avaya	Avaya Inc. designs, builds and manages communications networks for more than one million businesses worldwide, including more than 90 percent of the FORTUNE 500®. Focused on businesses large to small, Avaya is a world leader in secure and reliable Internet Protocol (IP) Telephony software applications, systems and services and driving the convergence of voice and data communications with business applications	Wireless: Voice Wireless 900 MHz Wireless Telephone Solution TransTalk™ 9000 Digital Wireless System DEFINITY® Wireless DECT System DEFINITY® Wireless Business System EC500 IP Wireless Telephone Solution Wireless LAN AP-3 Access Point AP-4 Access Point AP-5 Access Point AP-6 Access Point Wireless Outdoor Router System	www.avaya.com
Axonn	AXONN, LCC, is the worldwide leader in wireless packet data solutions. With over 6 million units in operation, AXONN's proven technology provides secure wireless data links for industrial, commercial, residential and remote monitoring applications.	AXONN offers four families of radio products: • Satellite Products • End-user products which can be easily connected by standard interfaces • Radio modules which can be integrated into existing or custom systems • Custom engineered radios	www.axonn.net
BearCom	BearCom is North America's largest provider of wireless communications equipment and tailored solutions.	BearCom offers sales and service of two-way radios from Motorola, ICOM and others.	www.bearcom.com
Boycetech Communications		We provide wireless voice services, data applications (java enabled), cellular phones, and two way radios. specialize in Nextel Direct Connect,	www.boycetech.com

Company Name	Company's Self Introduction	Company Service	URL
		Cellular services and all data applications.	
CenturyTel	ILEC Telephone Company serving Sab Marcos, Lake Dallas and Port Aransas TX	Provide voice and data solutions Nortel and Cisco distributor	www.centurytel.com
CES Network Services, Inc.	Established in 1988, CES has combined technical and organizational consulting expertise to offer a comprehensive, timely and high quality service to the public and private sector. Since 1988, we have been responsible for Wireless System Design & Analysis for Switching, Telephone Systems and RF and Audio Networks, FCC / FAA Licensing, RF Interfere Analysis, Tower Co-locations. We perform Installation, Test, Service, Support and Maintenance both nationwide and internationally.	• Network Strategy, Design and Engineering • Network Planning and Management of both wired and wireless (LAN, WAN & MAN) • RF Engineering and Propagation Studies • Design of Satellite networks (C, Ku and L bands) • Development of video (TVRO) and voice / data (VSAT) networks • Microwave Radio • Cellular / CT2 / 450, 800 Trunking & 900 Mhz / iDEM PCS System Engineering • Radio Traffic Control Network • Equipment for Voice / Data and Video applications	www.cesnetser.com
Christian Telecommunication Services	As a previous contractor for TXDOT, I am looking forward to doing business with you in the future. We have maintained and installed voice and data cabling, and data network systems at most of your sites in Houston and the surrounding areas.	We specialize in the installation and maintenance of voice and data cabling, data network systems, and phone systems.	
Cingular Wireless	Established over 16 years ago, under the name of Southwestern Bell Wireless locally, we are a merger between SBC and Bell South Mobility with a mature network. Currently offering TDMA and GSM digital technologies which provide significant benefits like strong voice quality & clarity, privacy & SECURITY, increased system capacity, extended battery life, text messaging capability.	wireless voice and data services	www.cingular.com
CMS Communications		Avaya, Nortel and NEC Telephone Equipment	www.cmsc.com
Communications Supply Corporation	CSC has over 600 employees, 27 warehouses, more than $60 million in local inventory, and 30 sales offices throughout the United States.	• Copper Cabling Solutions (Cat 6, 5e) • Fiber Optic Systems & Solutions	www.gocsc.com/houston

Company Name	Company's Self Introduction	Company Service	URL
		• Cable Management Solutions • Test Equipment • Tools & Installation Products • Power Protection • Low Voltage Specialty Cabling • Wireless Solutions • Outside Plant Products & Solutions • Networking Solutions Hardware • Voice Products	
Connection Technologies	Connection Technologies is a systems integration and technology consulting company located in Shreveport, Louisiana, close by the East Texas area.	• Wireless communications engineering, installation & support services • Video monitoring & surveillance systems • Local & wide area network systems • Consulting	
Cross Telecom Corporation	Cross Telecom is a Platinum Reseller for Avaya, and the fastest growing Avaya Reseller in the USA. Cross Telecom has (8) offices in Texas and Nationwide coverage.	Data Networking equipment, VOIP equipment, Call Centers, Avaya Wireless equipment, Video Conferencing equipment.	www.crosstelecom.com
Daniels Electronics Ltd.	Daniels Electronics Ltd. was incorporated under the Company Act of the Province of British Columbia December 12, 1950 and was organized to research, develop and manufacture radio communications equipment.	Daniels Electronics Ltd. specializes in the design and manufacture of modular AM / FM and Digital radio systems operating from 29 MHz to 960 MHz. • Modular, high reliability, high performance Low Band VHF / VHF FM / VHF AM / UHF / 800MHz and 900MHz continuous duty base stations and radio repeaters systems. • Solar cell powered mountain top Low Band VHF / VHF FM / VHF AM / UHF / 800MHz and 900MHz radio multi-linking systems. • Transportable VHF / UHF fire and law enforcement repeaters.	www.danelec.com
Datron World Communications	Datron World Communications is a division of the Titan Corporation. Datron is an equipment manufacturer that supplies voice and data radios.	Manufacturer of Guardian series of land mobile radios that are APCO Project 25 compliant	www.dtwc.com
ELPRO Technologies	ELPRO, based in Brisbane Australia, is a world specialist in radio telemetry technology - sending		www.elprotech.com

Company Name	Company's Self Introduction	Company Service	URL
	data and information by radio. The company utilizes the very latest design techniques to manufacture high quality data radios and microprocessor controllers, combined with industry proven, dedicated software.		
ENCOM Wireless Data Solutions Inc.	ENCOM Wireless Data Solutions manufactures a complete line of industrial-strength, spread spectrum wireless products for many applications, including Traffic Monitoring and Control (Intelligent Transportation Systems).	All ENCOM products include ControlPAKTM, the most comprehensive radio programming and diagnostic software in the traffic industry.	www.encomwireless.com
Enterprise Systems	Enterprise Systems a Nortel Networks Premium Partner is a National Distributor and is Head quartered in Houston Texas.	Enterprise Systems sells services and Maintains Meridian PBX Succession and Norstar Key systems. As well as a full line of Nortel Data products.	www.enter-sys.com
FastLinks LCC	FastLinks is an authorized QISV for the state of Texas. We specialize in the design, installation and support of wireless WANs.	We offer a full suite services aimed at meeting every customer's needs for wireless building to building LAN, voice and video connectivity. These services includes feasibility studies, system & path engineering, site surveys, FCC licensing, project management, turn-key system installation, and a host of comprehensive post-installation support services.	www.wirelesswans.com
harGIS LCC	harGIS LCC delivers mobile GIS solutions that dramatically improve field force productivity. By combining wireless communications, office systems connectivity, and location based services, the har*GIS TruckMap*™ product line gives mobile field crews and dispatchers the information and support that they need — when they need it.	Our professional services team provides all levels of implementation, development, integration and project management. We have special expertise with geo-spatial systems and GIS. We feature a low-cost, quick-implementation Benchmark service to provide a field trial system using your map data and forms. Business Partners include Trimble Navigation, ESRI, NexTel and Navigation Technologies.	www.har-gis.com
Harris Corporation	Microwave Communications Equipment and Services	Point-to-point microwave radio communications equipment. Engineering Design Transmission Engineering Installation Project Management Training	www.harris.com
Infiniti	ICT is an organization with deep roots of experience	Providing consistent superior service and quality	www.infiniticorp.com

Company Name	Company's Self Introduction	Company Service	URL
Communications Technologies, Inc.	in the communications industry…maintaining a staff with over 100 years of combined experience. Our customers' communications systems are designed, installed, and maintained to meet the demands of today and the challenges of tomorrow.	products stems from the ability to utilize personnel that are experienced and certified in many of the diverse backgrounds of our industry. Network Cabling Infrastructures, Fiber Optic Specialties, Video Systems, Computer Systems, Wireless Networks, Security & Surveillance Systems, and Outside Plant Capabilities are some of the interwoven aspects of communications ICT supports.	
Infinity Connections, Inc	Infinity Connections, Inc. is a full service network integration firm. From wireless networks to WAN or LAN projects, we can connect your company to the latest Technology.	Wireless Networks, Wide Area Networks, Local Area Networks, data drops, fiber and CAT5E cabling.	www.infinityconnections.com
InHouse Systems, Inc.	InHouse is a systems integration contractor specializing in CCTV and remote video surveillance, access control and wireless security and fire alarm monitoring since 1988. Authorized dealer for American Dynamics and Sensormatic.	Remote Video Surveillance, CCTV, Networking, Access Control, Security, Fire Alarm, Environmental Supervision, Wireless System Monitoring from U.L. facility.	www.safeandsound.net
Inter-Tel Technologies	A profitable 34 year old telecommunications solutions company with 63 direct offices nationwide.	• Wireless solutions via partnership with Spectralink. • Digital voice and data systems. • Audio and video systems. • Local and long distance service.	www.inter-tel.com
Intuicom	Intuicom provides next-generation wireless data networks optimized for real-time GPS and other data-critical applications.	Our wireless network systems are designed to satisfy the most demanding requirements for long range remote or mobile device networking.	www.intuicom.com
Looking Glass Networks, Inc.	Looking Glass Networks, Inc. can provide turnkey solutions to wireless communication and fiber optic projects. We have offices in the Houston and Dallas areas to accommodate all sizes of projects.	LGN can work with your firm to design, engineer and build your communication system. Our staff's experience includes engineering, material procurement, permitting, construction management, and construction. We have many vendor agreements to facilitate competitive pricing and quantity discounts.	www.lglass.net
Mercury Networks Inc	Mercury Networks Inc provides wireless communications including Free Space Optics and 802.11 based RF.	Mercury Networks Inc provides turnkey installation including site survey, site preparation, and training. We specialize in point to point Free Space Optics. We	www.mnitx.com

Company Name	Company's Self Introduction	Company Service	URL
		can provide up to 1 Gigabit per second links.	
Metrocall Wireless	Welcome to Metrocall Wireless, provider of wireless communication to keep you in touch.	Wireless 2way communication. Wireless email, Blackberry, and conventional paging service (alpha text and digital numeric).	www.Metrocall.com
Metroplex Two Way Radio	Metroplex Two Way Radio is a women-owned company certified by both the State of Texas as well as the North Central Texas Regional Certification Agency (NCTRCA). Our company was founded in 1982, and we are a leader in the Dallas/Ft. Worth area for service and sales of Two Way Radio Systems. We provide Two Way Services for DFW Airport, DART, Town of Highland Park, and many other city and government agencies as well as commercial customers.	Two Way Radio parts, sales and services as well as community repeater services. Para transit mobile radio repair and dispatch.	www.mtwr.com
Mobile Phone of Texas, Inc.	We have been in business since 1965 and have offices in Abilene, Wichita Falls and Mineral Wells and have provided communications services to the DOT and various other state agencies for most of those years/.	1-way and 2-way pagers, 2-way radio, answering service, cellular (Cellular One and Sprint) and NEXTEL.	www.abilene.com/pageone
Nationwide Tower Company	Incorporated under the laws of Kentucky in February of 1987, Nationwide Tower has played an integral part in the infrastructure of microwave, CATV, cellular, wireless and broadcast markets.	Inspect-Repair-Re-guy-Lighting-Paint-Antennas-Feedlines-Structural Analysis-Erect-Dismantle-Line Sweeping-Co-locates-New & Pre-owned Towers & Monopoles-Light & Site monitoring services-Tower Tracker Service-Cathodic Protection of Guyed Tower Anchors	www.nationwidetower.com
NEC Business Network Solutions	NEC Business Network Solutions, Inc. (NEC BNS) is a multiservices systems integrator and NEC America's direct sales and service organization. NEC BNS is a Cisco Systems Gold Certified Partner.	NEC BNS provides end-to-end voice, data and video communication network solutions; and offers planning, designing, procurement, implementation, operational support, management and monitoring services-enabling its customers to be more productive, competitive and profitable.	www.necbns.com
Nextel			www.nextel.com
Nortel Networks			www.nortelnetworks.com
Oel Worldwide Industries, LCC	We provide installation tooling	Tools and supplies for wireless installation	www.oelsales.com

Company Name	Company's Self Introduction	Company Service	URL
Omega Electronics	Omega Electronics is a commercial two way radio sales and service provider.	Commercial two way radio sales, repair services, installation and support services	www.omegaelectronicsonline.com
One Source Building Technologies, TYCO Electronics	The OneSource Building Technologies (BT) Wireless Solutions Group, a division of TYCO Electronics, provides wireless local area network (WLAN) and wireless wide area network (WWAN) communication solutions for Industry, Education, Medical and Government.	Wireless Local Area Network (WLAN) Features • Extend existing wired local area networks to hard to cable areas • Eliminate Move, Add, Change expenses • Enable roaming in and around your facilities • Combine Wireless Data and Voice over the same Wireless Network • 11Mbps-2.4GHz; IEEE 802.11b compatible • 54Mbps-5.8GHz; IEEE 802.11a compatible Point-to-Point Wireless Wide Area Network (WWAN) Features • Extend existing Fiber connections • Last Mile access where fiber can't reach • Enable redundancy to existing Fiber • Supports Data, Voice and Video applications • Unlicensed, Digital Spread Spectrum radio, 11Mbps to 1Gbps (2.4GHz and 5.8GHz) • Licensed Digital Microwave radio, up to 100Mbps (18, 23, 24 and 38GHz) • Supports all major Ethernet protocols • Distances up to 15 miles Point-to-Multi-point Wireless Wide Area Network (WWAN) Features • Connect multiple Networks within a campus environment • Unlicensed, Point-to Multi-point, Digital Spread Spectrum radio (2.4GHz and 5.8 GHz) • Supports all major Ethernet protocols • Free Space Optics (FSO) technology from 10Mbps to 2.5Gbps (OC-48) up to 1 mile.	www.onesourcebt.com
Operational Technologies	OpTech is a multi-disciplined corporation of professionals and technicians providing top quality	Telecom & Federal EF&I - engineering, wireless, wireline, optical and Wi-Fi installation, furnish of	www.otcorp.com

Company Name	Company's Self Introduction	Company Service	URL
Corporation	services to clients in the following areas: Supply Chain Management, International Business, Telecom & Federal EF&I, Information Security & IT, Environmental & Life Science and Personnel Research.	telecom equipment & materials; project mgmt.	
Paradigm Traffic Systems, Inc.	Paradigm Traffic Systems, Inc. is a provider of traffic system solutions and is involved in system design and integration as well as product sales and support.	Paradigm typically works with TxDOT personnel to integrate various traffic equipment into new or existing infrastructures; frequently choosing wireless communications methods. Paradigm is involved in projects throughout Texas which include large detection projects in major metropolitan areas.	www.paradigmtraffic.com
P-Com, Inc	P-Com develops manufactures, and markets Point-to-Multipoint, Point-to-Point, and Spread Spectrum radio systems for the worldwide telecommunications market.		www.p-com.com
Pexx, Inc.	Our primary business id networking with special emphasis on wireless networks, both outdoor and indoor.	Site surveys (with Spectrum Analysis), design, installation, trouble shooting, repair and maintenance of wireless networks.	www.pexx.net
Psion Teklogix Corporation	Psion Teklogix develops, implements and supports mobile computing solutions for warehousing, distribution, transportation and logistics and mobile data collection.	Manufacturers, repairs, support wireless data devices.	www.psionteklogix.com
Quality Network Service Inc	Quality Network Services, Inc (QNSI) was founded in May 1999 as a full service EF&I organization, headquartered in Austin, Texas.	QNSI provides comprehensive wireless services to include: • Site evaluation and construction • Zoning and permitting • Installation • Skidding • Commissioning • Project planning and management • Tower and Antenna installation • Warehouse services Quality Network Services provides tower erection and maintenance services, along with antenna change	www.qnsi.net

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		outs, repairs and maintenance and provides turnkey installation on Microwave Systems.	
R.T.C., inc.	RTC is an authorized Motorola service center as well as a dealer, agent and manufacturer's representative for providing two-way radio equipment.	Provider of 2-way radio equipment and hardware. Provider of installation of said equipment. Provider of repairs and services to include microwave, tower work and 2-way radio services.	
RedMoon Broadband	The dawn of RedMoon high-speed Internet is here. Pioneers in wireless broadband technology, RedMoon specializes in Wireless High-Speed Internet Networks and Public Hot Spots.	We provide discounted T1s, Wireless High-Speed Internet Networks, cable modem networks, Hot Spots, as well as other emerging technologies.	www.redmoonbroadband.com
R-Tel Communications, Inc	R-Tel is a premium provider of Avaya, Nortel and Siemens/Rolm products in the Texas market. We have support staff in the DFW, Houston/Beaumont, Austin/San Antonio, and Sub-contractors in the remainder of the state.	R-Tel provides communication equipment from Avaya, Nortel, Siemens/Rolm, and ESI. We install and service on T&M as well as full service maintenance contracts. We also provide cabling infrastructure, inside and outside plant including fiber optic.	www.rtelcom.com
Rx Technology	Rx Technology is the largest provider of commercial high speed wireless broadband internet access, VPN and point to point services in the San Antonio and South Texas area.	Cisco Premier Partner - Wireless Certified. Surveillance cameras, Construction Site Hot Spots. Networking, Fiber Optic Cabling Certified.	www.rx-tech.com
Sprint PCS	Sprint's Nationwide PCS Network is the nation's largest all digital wireless network covering a population of over 257 million people, including affiliates, or nearly 87% of the country. Sprint is the fourth largest wireless carrier in terms of customers with approximately 18 million direct and resale subscribers.	Wireless voice and data services. Voice phones include PDA's with both Palm and Windows operating systems. Connection card technology that allows laptops to access the internet using an industry leading 4 different modem technologies. In addition we have secure end to end solutions (Data Link) for highly secure and redundant needs using either frame relay or VPN technology. Sprint PCS also has developed a telemetry group by partnering with many industry leaders in the following area: • Mobile Resource Management • Financial Transaction • Automated Meter Reading • Energy Management • Asset Management	www.sprintpcs.com

Company Name	Company's Self Introduction	Company Service	URL
		• Security • Medical • Transportation	
STV Communications		Install towers, wireless systems.	www.stvcommunications.com
Talk-A-Phone Co.	Talk-A-Phone is a Communications Manufacturer based in Chicago. We have been providing communication solutions across the globe for over 65 years.	Emergency Phone Networks, Help Points, Area of Rescue systems and accessories. Integrated solutions including CCTV, wireless, access control, Public Address, etc.	www.talkaphone.com
TCS Consultants, Inc.	TCS was founded in 1986 originally developing software for the telecommunications industry. We have now grown into doing the system design work, providing the equipment and constructing the system.	• Path & Site Surveys • RF Propagation Analysis • System Evaluation & Design • Project Management • Technical Training • System Installation • Tower and Antenna Inspection, Install & Maintain	www.tcstx.com
Technology For Education	TFE has a reputation as a premier network integrator of data, voice and wireless communication products in Central Texas. Our customers credit our success to being a technical resource and for the planning, implementation, and support of their network needs.	TFE has the capability to design and implement local and wide area networks. We support all requirements for servers, workstations, cabling systems, and communication devices. The TFE team is comprised of Novell® and Microsoft® Engineers. TFE can also provide high-level technical expertise before you undertake a network design, upgrade or integration project. Our network engineers can help you define your requirements, develop a sound technology strategy, assess the fit of new applications and their impact on your network, and determine which products and technologies meet your business objectives. The specific LAN/WAN services we offer include: • Detailed need analysis • Site audit • Strategic planning • Product recommendations	www.tfe-waco.com

Company Name	Company's Self Introduction	Company Service	URL
		• Design and implementation • Full installation of networking hardware and software • VPN Network management	
Teletouch Communications, Inc.	We provide Wireless Communications Equipment and Service.	Wireless Satellite and other Wireless Technologies.	www.teletouch.com
Texas Communications	30+ years in Private Wireless products and services. Austin, TX location is QISV vendor	• 2 way radio turn key systems • SCADA and other data related systems • Mobile Data Systems • Dialup Internet • Wireless Internet	www.texascom.com
The Cambridge group	We are a manufactures rep firm for the communication industry for land, mobile and radio products.	We provide goods and information on several lines, Crescend - high power amplifiers, EMR Corp - filters, duplexors, Isolators, BDA's. Ga-tronics Corp - Repeater controllers, Interconnects, Local & tone remotes, desk sets and RF call boxes. NABC provides various types of batteries, LMR rechargeable and alkaline. Kenwood Communications - various two-way and mobile radios along with repeaters, GPS and AVL systems. Manning Navcomp - AVL, GPS mapping systems. Otto Communications - profesional quality headsets, speaker mics, lapel and palm mics. Pyramid Communications - UHF/VHF Synthesized Vehicular repeaters, GPS/AVL systems, Inband SVR options. Radiall/Larsen - Portable, mobile and ase station antennas, PCS, cellular, data, LMR, SMR and GPS antennas. Trident Micro Systems - Logic controller products. Watson Dispatch - communications console furniture.	www.cgwireless.com
T-Mobile Wireless	GSM Wireless Voice Communications and GPRS Wireless Data Connection	Provider of voice and data communications including Blackberry Data Devices, Pocket PC Devices, and Unlimited Mobile to mobile rate plans and unlimited Data plans.	www.t-mobile.com
Trillion Partners, Inc.	Trillion is a leading provider of ""last mile""	Wireless wide area (WWAN) networks, WWAN	www.trillionpartners.com

Company Name	Company's Self Introduction	Company Service	URL
	broadband connectivity and high-speed Internet access for K-12 schools, government and municipalities, healthcare systems, libraries and colleges and universities.	engineering, WLANs & Engineering, network management services, and converged services over WWANs (voice, video & data).	
TVi Dish		Satellite TV and high speed two way satellite internets.	www.tvidish.com
TVi Dish	Local Satellite internet dealer in the Greater Austin/Georgetown area including rural.	We sell service and install StarBand satellite internet service. Business class service with over 1Mbs downloads and up to 150Kbs uploads. Static IP and VPN.	www.tvidish.com
Vibes Technologies	Remanufacturer of Nortel, Avaya, Cisco & Executone telecommunications parts and systems. Also provide Repair services and complete systems. We are a Nortel Premier Partner for Upgrades & New product.	Remanufactured & new Nortel (Meridian & Norstar), Avaya, Cisco, & Executone products. - Repair facility for all listed products. - Provider of peripheral products such as headsets, audio conferencing, CSU & DSU, & Etc.	www.vibestech.com
Victoria Communication Services, Inc.	VCS is a full sale and service center for two-way radios and cellular phones	Complete sales and service	www.viccomm.com
W.T. Services, Inc.	W.T. Services, Inc. has been in business since 1982. We have four locations in the Texas Panhandle, Hereford, Amarillo, Borger and Plainview. Our business consist of Two-way radio communications, telephone companies (Friona & Bovina) Area wide paging(Panhandle of TX), Cablevision (Friona & Bovina) and Internet, Wireless Internet	Sales, Service, Communications System Design and Installation of Communications Equipment, Wireless services, telephone systems.	www.wtservicesinc.com
Wave Wireless Networking	Wave Wireless Networking is a nine year old manufacturing company specializing in delivering "last mile" connectivity for high-speed Internet and intranet access using outdoor fixed wireless solutions. Our highly secure broadband routers with AES (Advanced Encryption Standard) were touted at the TOPPOFF2 exercises earlier last month and have been deployed in various FAA and government projects throughout the country.	2.4GHz wireless routers 18GHz licensed microwave 23GHz licensed microwave Our routers provide secure transmissions as required by government and private enterprises.	www.wavewireless.com
Wear Radio Service Inc	Authorized Motorola, Zetron dealer. Specialists in two-way radio design, sales & service. Installation of	Repairs of two-way equipment. 24 hour technicians.	www.wearradio.com

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	equipment including police packages tower construction and service. Support 911 systems. Qualified mobile Vision (video camera) service.		
Western Communications	Western Communications was established in 1936 in San Angelo, Texas. The company takes pride in providing local customer support in the markets we serve and has a loyal customer base.	The company provides paging service, dialup Internet service and high-speed wireless DSL Internet service.	www.wcsonline.net
Wireless Dynamics	A premier Fixed Wireless Broadband company serving Texas. Small to large fixed wireless deployments using both TCP/IP and ATM protocols. QISV qualified.	Consulting, Engineering, and Turn-key project implementation.	www.wdynamics.net
Xeta Technologies	Xeta Technologies is a leading provider of integrated communications solutions. We are publicly traded company with over 20 years experience.	Xeta Technologies provides integrated solutions including: traditional voice and data products as well as converged systems such as VoIP, wireless, contact centers, unified messaging and video solutions. Further we can deliver the technology to maintain one set of applications that can be delivered to wired and wireless users using a diverse set of small screen wireless devices.	www.xeta.com