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TELECOMMUNICATION TECHNOLOGY: OVERVIEW OF THE PROS/CONS

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INTRODUCTION

Telecommunications usually becomes the cost dominant element in the design of automated traffic data acquisition for traffic control systems. An almost bewildering array of technologies is now available to fulfill data transmission requirements.

The transportation professional needs to understand how to select telecommunications technologies to meet site specific requirements.

This paper describes the advantages and disadvantages of several existing and emerging technologies (both hardwire and wireless) when applied to data acquisition in traffic control systems. The paper should prove useful to the designer in making the appropriate analyses and tradeoffs for a telecommunications design.

TELECOMMUNICATIONS FUNCTIONS

The telecommunications system serves as the traffic control system's backbone for transfer of information among system elements. Telecommunications functions include:

- Issue commands to field components such as closed circuit television (CCTV), changeable message signs, highway advisory radio, ramp meters, traffic signal controllers, and detectors.
- Receive verification that field units have received and reacted in accordance with commands.
- Receive traffic data from sensors.
- Monitor operational status of field equipment.

It may also be necessary to communicate with other traffic operation centers in the region.

TELECOMMUNICATIONS MEDIA TYPES

Table 1 presents various telecommunications media that can be considered for data acquisition in a traffic control system.

Until the mid 80's owned twisted wire pair was used in the majority of traffic control systems. Leased voice grade telephone lines were also used to substantially reduce the capital cost of the telecommunications system. However, substantial increases in leasing costs led to the decline in the use of leased lines. In the 1980's, many traffic control systems, especially freeway traffic management systems, used coaxial cable, since its wide bandwidth allowed transmission of CCTV along with extensive data.

More recently, fiber *optics* has emerged as the leading hardwire interconnect. Also finding application in traffic control systems are *area radio networks, terrestrial microwave, spread spectrum radio, cellular radio, packet radio,* and *satellite systems.* Characteristics of each of these will be described with respect to application to traffic control systems.

Fiber Optics

Fiber optics has become the media of choice for most traffic control applications. Fiber optics cable, first used in the telecommunications industry, transmits information by propagation of light rays through a fiber core. Fiber optics has an extremely large information carrying capacity or bandwidth. Since the late 1980's, most traffic control systems using owned cable facilities require a high capacity land line communication backbone (since CCTV transmission is usually a requirement) and have therefore deployed fiber optics cable. Table 2 lists major advantages and disadvantages of fiber optics communications.

The cost of installing and maintaining fiber optics communications has decreased substantially, making it a good choice for telecommunications. Fiber optics cable has been installed on the Highway 401 project in Toronto, Canada (1990), the Shirley Highway Extension in Virginia (1990), and recently in Seattle, San Antonio and Houston.

Area Radio Networks

Area radio networks refer-to owned wireless interconnect systems that broadcast signals to an area rather than a specific location. Table 3 lists the major advantages and disadvantages of radio telecommunications systems in general while Table 4 shows the advantages and disadvantages of area radio networks.

The Lancaster, California traffic signal system uses an area radio network.

Table 1
Media Types

- Hard wire
  - Fiber optics
  - Owned twisted wire pair
  - Leased voice grade telephone lines
  - Coaxial cable
- Wireless interconnect (owned)
  - Area radio networks (ARN)
  - Terrestrial microwave links
  - Spread spectrum radio (SSR)
- Wireless interconnect (commercial)
  - Cellular radio
  - Packet radio
  - Satellite

Table 2
Advantages and Disadvantages of Fiber Optics Communications

ADVANTAGES	DISADVANTAGES
• Relatively insensitive to environmental changes and electromagnetic interference. • Low maintenance requirements. • Frequent repeaters not required (can go 5 to 10 miles depending on characteristics of fiber and number of splices).	• Requires more skilled technicians to install and maintain. • Multiplexing/Demultiplexing equipment can prove expensive depending on standards used. • Typically incurs high capital cost for installation. • Installation may not be survivable during roadway reconstruction.

Table 3
Advantages and Disadvantages of Radio Communications Systems

ADVANTAGES	DISADVANTAGES
• No need for physical medium since signal propagates through atmosphere. • No cost of hardwire installations and maintenance. • Can span natural barriers or provide communications link between points where rights-of-way are not available. • Flexible implementation • Commercial off-the-shelf equipment available. • Used in a number of traffic control systems.	• Relatively complex design (compared to land line communications system) since the local operating environment (e.g., terrain, potential sources of interference, available frequencies, etc.) must be investigated and taken into account as part of design process. (However, a variety of theoretical models can be used to predict radio wave propagation for a given set of conditions.) • Limited choices of operating frequencies based on regulatory issues. • Path line of sight constraints (e.g., in the microwave region of 900 Mhz and above, line of sight to the receiving antenna(s) generally required). Propagation relationships govern the actual clearance required of obstacles and adjacent structures. • Fading considerations. • Turnaround time considerations. • Limited bandwidth. • Requires external antennas and cable. • May require repeaters.

Table 4
Advantages and Disadvantages of Area Radio Networks (ARN)

ADVANTAGES	DISADVANTAGES
• Can operate traffic controllers or other traffic control devices. • Can provide voice communications to highway maintenance vehicles. • Can propagate into built up areas and buildings. • Can support 9600 baud data rate. • Can prove cost effective depending on application.	• Terrain may limit range. • Limited channel availability in urban areas. • Requires antenna at each controller site. • Turnaround time excessive for some applications. • Service reliability may limit use for some applications.

Terrestrial Microwave Link

Terrestrial microwave links are owned, wireless communications media. Microwave is used primarily as a communications point-to-point trunk, carrying voice and data, and limited CCTV.

Table 5 lists advantages and disadvantages of a terrestrial microwave link applied to traffic control systems.

Spread Spectrum Radio

Spread spectrum radio is another owned, wireless interconnect medium. Spread spectrum radio (SSR) refers to a communications technology that spreads the signal bandwidth over a wide range of frequencies at the transmitter and then compresses it to the original frequency at the receiver. The military originally developed spread spectrum radio during World War II to resist enemy radio interception and jamming. Several deployments are now underway using it as traffic control system interconnect.

Table 5
Advantages and Disadvantages of Terrestrial Microwave Links

ADVANTAGES	DISADVANTAGES
• Useful as a point-to-point trunk. • Can transmit data and a limited number of full motion video channels. • Can control groups of traffic control devices. • Can use both analog and digital transmission.	• Requires line-of-sight path. • In most cases, requires FCC license. • Channel availability limited. • May have little choice in operating frequency. • Possible interference due to rain, snow and atmospheric effects. • May require antenna tower. • Available bandwidth usually limited.

Table 6 presents the advantages and disadvantages of spread spectrum radio.

Cellular Radio

Commercial cellular radio represents another possible wireless interconnect medium. To date, cellular radio has been used only in a few small scale and short term traffic control applications. However, recent announcements regarding new data services on the existing analog cellular network may increase the applicability of this medium to traffic control. Table 7 summarizes advantages and disadvantages of cellular radio communications for traffic control.

Packet Radio

Packet radio is another commercial wireless medium that can be used for traffic control system interconnect. Unlike cellular radio, packet radio services were designed for data transmission rather than voice communications. Based on the developments discussed in the previous section, the line between packet radio and cellular radio begins to blur as cellular radio implements features supporting both voice communications and packet data.

Table 8 shows advantages and disadvantages of packet radio service.

Table 6
Advantages and Disadvantages of Spread Spectrum Radio

ADVANTAGES	DISADVANTAGES
• Very flexible installation.	• New technology for traffic control and traffic surveillance application.
• Does not require cable installation and maintenance.	• Uncertain range (0.3 - 6 miles), function of area topography.
• Does not require FCC channel use approval in 902-928 Mhz band.	• Higher bandwidth than radio fixed frequency transceivers.
• Works extremely well in a high noise environment.	• Required external antenna and cable.
• Currently in use for many industrial process control applications.	• Requires more sophisticated equipment and specialized technicians.
• Uses low transmitter power.	• Unprotected channel space.
• Can be used in a mixed system of wired or radio interconnected controllers.	
• No land line interconnect requirement.	
• Relatively low equipment cost.	
• Potential for broad range of traffic control system applications.	

Table 7
Advantages and Disadvantages of Cellular Radio

ADVANTAGES	DISADVANTAGES
• May prove cost effective for infrequent communications.	• *Airtime* cost excessive for continuous communication service.
• Eliminates need to connect to Telco service point or provide owned land line.	• Only two providers in any one area.
• Effective for controlling portable changeable message signs.	• Actual data throughput reduced due to protocol overhead.
• May prove effective for temporary installations.	• Remote areas may not have service.
• Cellular modems available off-the-shelf.	
• Network covers 93% of U.S. population.	

Table 8
Advantages and Disadvantages of Packet Radio Service

ADVANTAGES	DISADVANTAGES
• Designed for data transmission.	• Not cost effective for continuous communication.
• Cost effective for short messages.	• Not cost effective for lengthy file transfers.
• Can eliminate need for leased or owned land line.	• Service currently limited to major cities.
• At least two major providers.	• Time delay in delivering packet.

Satellite

Satellite communications is a third type of commercial wireless service that can interconnect traffic control systems. The current generation of satellite equipment and services has generally not proved cost effective for communications *local* is nature, typically required by traffic control applications. Designers should consider satellite communications for traffic control systems spanning large distances, e.g. regional. Table 9 summarizes advantages and disadvantages of satellite communications.

Satellite communications architecture uses earth stations to transmit and receive data via a geosynchronous (i.e., appears to remain in a fixed position in space) satellite positioned approximately 22,300 miles above earth. Specifically, an earth station modulates the baseband signal to the appropriate power and transmission frequency. Then, it radiates the signal to the satellite. The satellite shifts the received signal's frequency, amplifies it, and then reradiates the signal back to earth where it can be received by earth stations in the coverage area.

DESIGN CONSIDERATIONS

Recent experience indicates that CCTV requirements represent the governing factor in designing telecommunications for traffic control systems. Recent advances in compression of video signals in turn dramatically impact interconnect bandwidth requirements.

Video compression techniques take advantage of data redundancy and human visual limitations to reduce the transmission bandwidth required to transport video signals. *Interframe coding* techniques eliminate redundancy between successive frames by transmitting only the differences between frames, while *intraframe coding* eliminates redundancy within a video field. For example, video compression may result in transmission of 12 frames per second rather than the 30 frames per second.

Today, video compression finds use most widely *with videoconferencing* systems, which package the algorithms as part of video coder-decoders *(codecs,)* that convert analog video into a digital signal. A full-bandwidth analog video signal requires approximately 4.2 MHz of bandwidth, and nearly a 45 Mbps channel when digitized. Compression allows transmission of a full motion digitized video signal at rates as low as 56 Kbps, although **extremely low rates** may result in noticeable video quality degradation.

The cost of video codec equipment continues to decrease, and the demand for consumer products that use video codec technology will likely increase rapidly.

Table 9
Advantages and Disadvantages of Satellite Communications

ADVANTAGES	DISADVANTAGES
• Cost of circuits independent of their length.	• Not proven cost effective for local type communications (not long haul).
• Cost effective for long-haul circuits.	• Limited number of service providers.
• Downlink signals can be received over a wide area (e.g., United States).	• Channel leasing costs subject to increases.
• Cost effective for point-to-multipoint distribution applications (e.g., cable TV).	
• Uplink signals can originate over a wide area.	
• Flexibility for *quick setup* or mobile applications.	

Codec provides video quality sufficiently high for traffic monitoring applications without the need for owned land lines. Where only critical locations require TV surveillance, codec becomes an attractive alternative. For example, where a freeway traffic management system uses spread spectrum radio or leased lines for data applications, the communications network could transmit codec information from several cameras to the control center. The capitalized cost of such a system may prove lower, in many cases, than for a communication system based on owned land lines.

NEED FOR SELECTION PROCEDURE

Telecommunications for data acquisition in a traffic management system often proves the most complex aspect of system design. As seen in the previous sections of this paper, a wide array of available technologies exists. Thus, a standardized guide and selection process would prove helpful to the designer. Dunn Engineering Associates prepared for the Federal Highway Administration the *Communications Handbook for Traffic Control Systems* (1) whose purpose is to assist engineers in specifying traffic control system communications media, technologies, and architectures which are both compatible and cost effective.

Selection Techniques, Chapter 11 in the handbook, assists the system designer in selection of appropriate communication architectures and technologies. It presents procedures as a complete series of steps, but the designer can use a smaller subset in any given case. The process results in a preliminary communications system design. A detailed design will normally follow the technology selection provided by the methodology described in the next section of this paper.

SELECTION TECHNIQUES

A transportation professional needs a methodology for selecting compatible marriages between technology and architecture. Often, several technologies can serve in a traffic control system depending on the function performed by each communications link. The designer needs a general guide in procedure to assist in selecting the appropriate communications architecture and technology for a cost effective communications system.

Figure 1 shows the step-by-step process presented in the *Communications Handbook for Traffic Control Systems.* Following the detailed steps identified in Figure 1 will assure that site specific requirements are taken into consideration in selecting the right communications architecture and technology.

CONCLUSIONS

This paper has examined various media types that can be selected as the telecommunications system for data acquisition in a traffic management system. Recent experience indicates that:

- Telecommunications system design is critical to successful data acquisition in a traffic control system.

- The transportation professional needs to understand basic telecommunications functions to perform the appropriate trade studies.

- The *Communications Handbook for Traffic Control Systems* provides a step-by-step procedure for selecting the appropriate communications system.

- Technology and available services are evolving rapidly.

- Wireless communications techniques are becoming increasingly important.

- Fiber optics is becoming the hardwire interconnect of choice.

- Use of data compression for TV transmission is increasing.

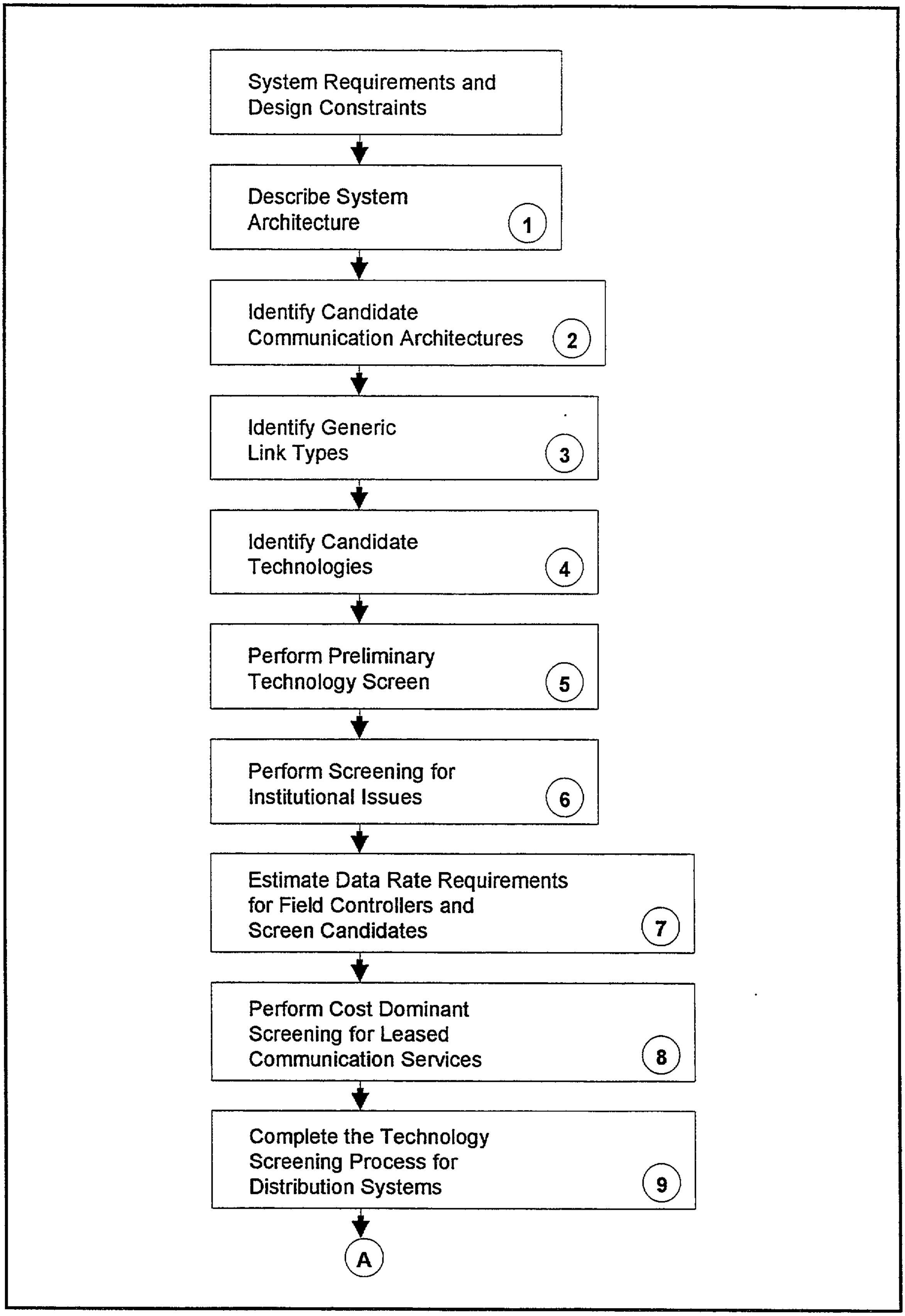

Figure 1
Procedure for Selecting Communications Architecture and Technology

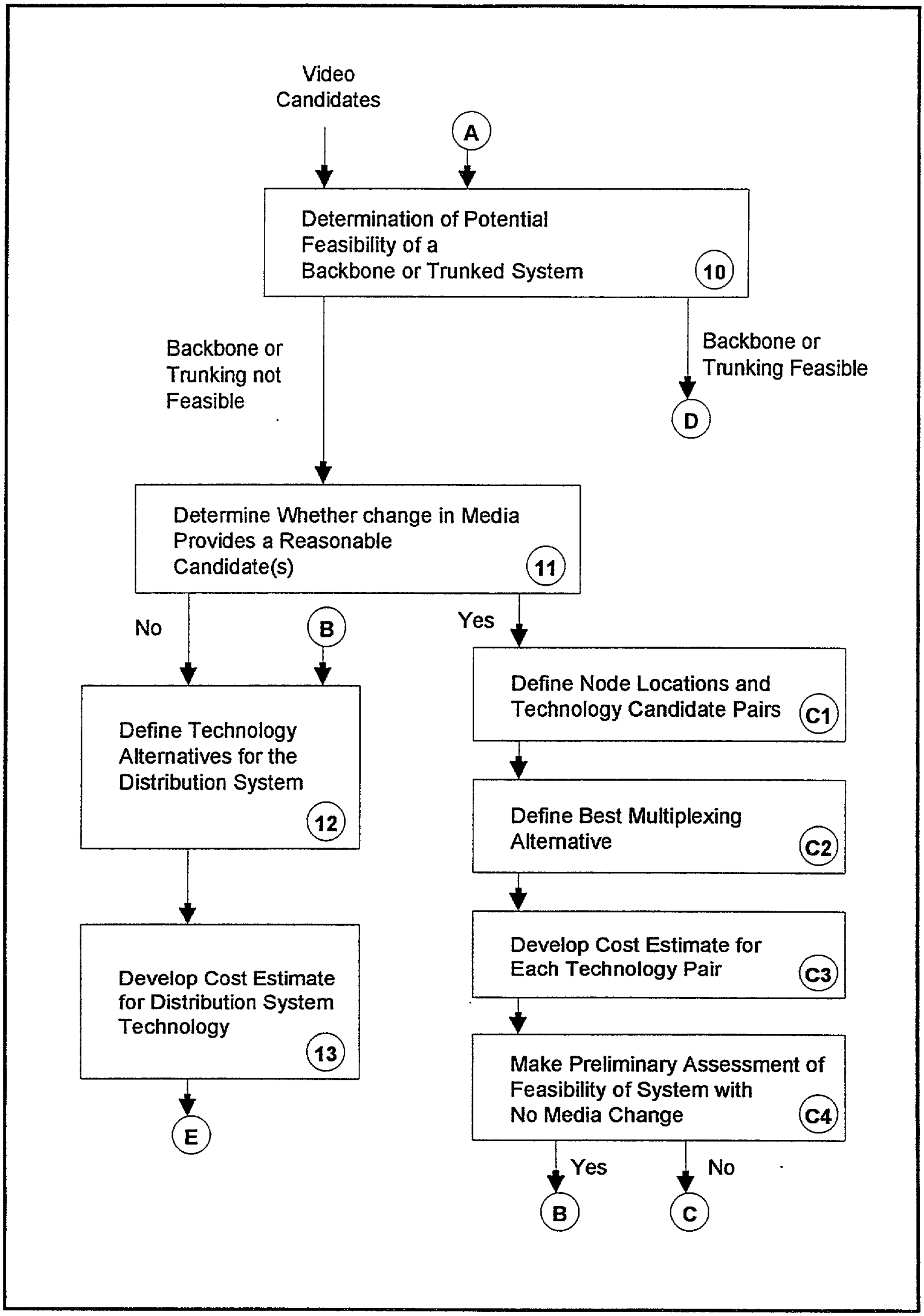

Figure 1 *(Cont'd.)*
Procedure for Selecting Communications Architecture and Technology

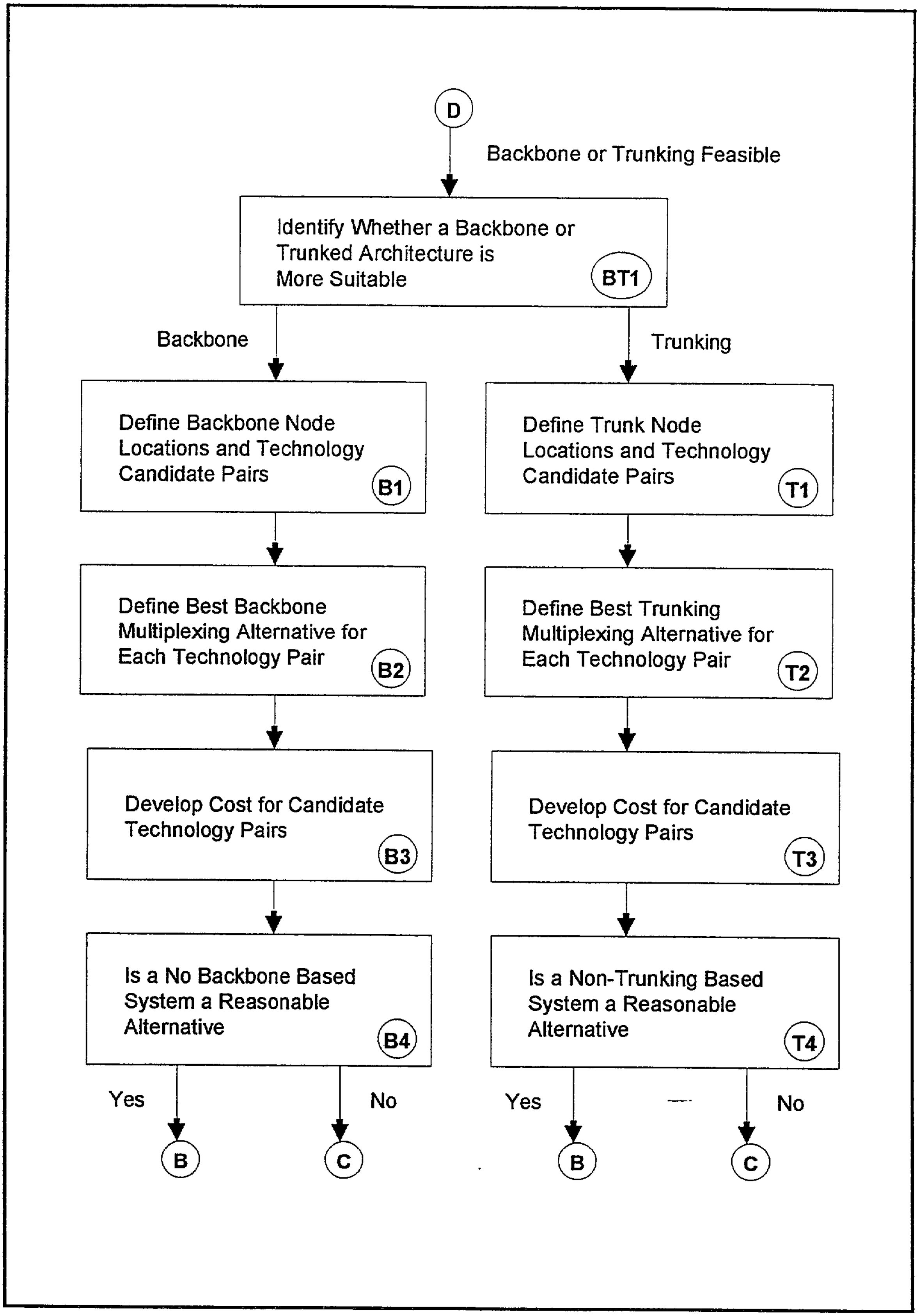

Figure 1 *(Cont'd.)*
Procedure for Selecting Communications Architecture and Technology

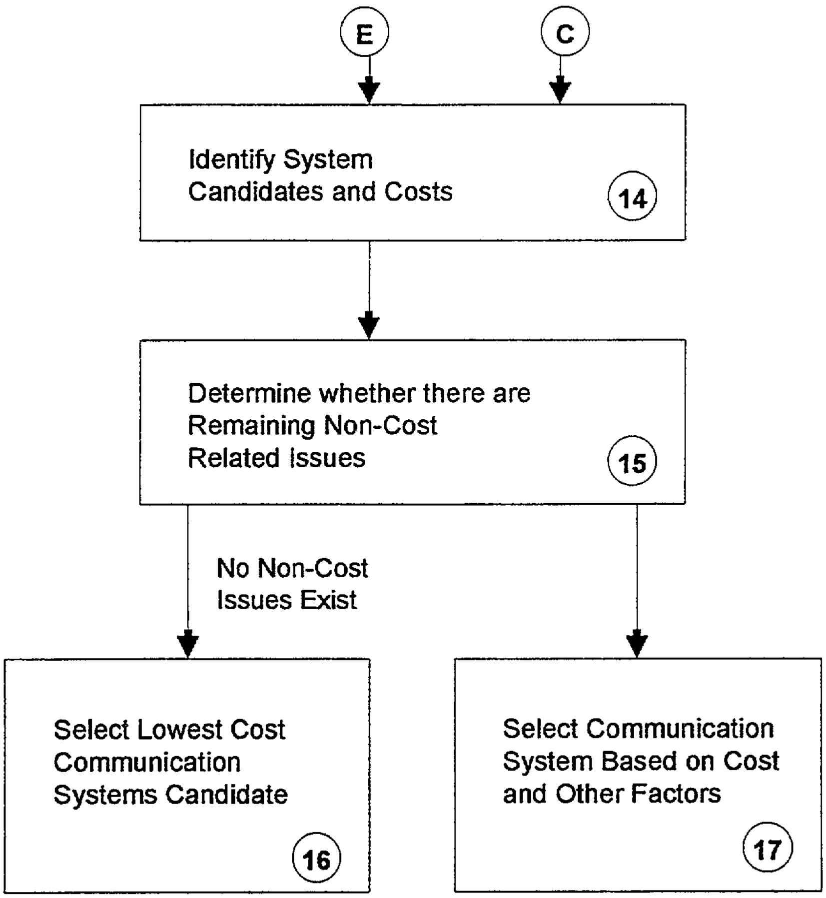

Figure 1 *(Cont'd.)*
Procedure for Selecting Communications Architecture and Technology

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ELECTROMAGNETIC EFFECTS ON TRANSPORTATION SYSTEMS

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Electromagnetic Effects on Transportation Systems

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Abstract

Unless properly accounted for in design, electromagnetic environments will have adverse effects on the operation and maintenance of intelligent transportation systems of the future. Electronic and electrical system protection design can be used to eliminate deleterious effects from lightning, electromagnetic interference, and electrostatic discharges. The evaluation of conventional lightning protection systems using advanced computational modeling in conjunction with rocket-triggered lightning tests suggests that currently used lightning protection system design rules are inadequate and that significant improvements in best practices used for electronic and electrical system protection designs are possible. A case study of lightning induced upset and failure of a railway signal and control system is sketched.

Introduction

The increasing reliance of modem transportation systems on increasingly sensitive electronic technologies is a trend that will continue well into the next century. The electronic-based technology elements include sophisticated computers, a broad range of sensors (video cameras, laser detectors, infrared sensors, microwave antennas, etc.), and hardwired and electromagnetically linked telecommunication systems. These elements will be subjected to potentially interfering effects from naturally occurring or manmade electromagnetic environments such as lightning from thunderstorms, air or **land** vehicle radio transmissions, or possibly intentional electrical disruption. These elements can be vulnerable to such electrical interference. Connectivity of regional systems to form large distributed transportation systems, encompassing states or regions of the country, will become more prevalent. Centralized information processing at control centers that operate air traffic, railway, and highway systems potentially will become more susceptible to interference from the increased area of coverage and from the trend to more sensitive electronic components.

Interruption of transportation system operations can have high safety and economic consequences. Because air traffic and railway system operations have been adversely impacted by lightning from thunderstorms, costly upgrades to existing systems are now underway. Future intelligent transportation systems can benefit from the lessons learned from recent evaluations of conventional lightning protection systems, and electronic and electrical system protection controls can be implemented early in the design phase of the system. An electronic and electrical protection retrofit or upgrade is usually much more expensive and less effective when compared with implementation of the protection in the design phase. Experience has shown that lightning protection system upgrades to fielded systems can cost up to 20% of the cost of the installed system compared with negligible costs if the protection is considered up front in the design phase.

Broad Spectrum Electromagnetic Effects

Robust protection of electronic and electrical systems from spurious electromagnetic environments requires consideration of all interfering sources that the system will encounter during its lifetime. For example, design and insertion of protection features for lightning will not necessarily provide protection against upset from electromagnetic sources such as transmitting radios or radar. Electromagnetic radiation susceptibility testing is routinely conducted in anechoic chambers and in mode-stirred chambers. A variety of analytical and computational techniques are available for theoretical assessments of electromagnetic radiation vulnerability of systems and components. These include PATRAN™ for structural/geometric modeling input, PV-Wave™ for output display and visualization and computational analysis codes such as THREDH and EIGER. Electrostatic discharge testing of systems and components is a well developed discipline that is detailed elsewhere. Only lightning effects on systems and components is covered in detail.

Lightning Effects and Protection

Perhaps the most pervasive requirement for electromagnetic protection in distributed transportation systems is for the effects of lightning from thunderstorms. Transportation systems are required to operate reliably both during and after thunderstorm activity. Over the past eight years, Sandia has conducted a rocket-triggered lightning test program to evaluate the performance of conventional lightning protection systems and to provide data to validate finite-difference, time-domain computer codes and simple analytical models used for the evaluation of such systems. Although these tests have been concentrated on earth-covered storage structures used for explosives and weapons, on maintenance-and-assembly buildings used for explosives assembly and disassembly operations, and on temporary lightning protection systems used in field operations, the results suggest that conventional lightning protection systems used in such situations are ineffective and that the electromagnetic environment associated with flashes attaching to such structures are best controlled in ways other than installation and maintenance of a conventional lightning protection system. Rudimentary details, as well as quantitative and qualitative information, is given to support these contentions.

Rocket-Triggered Lightning Testing of Weapon Storage Structures

In the summer of 1991, rocket-triggered lightning tests were conducted on an earth-covered weapon storage structure at Ft. McClellan, AL. Detailed results of the tests are given in References 1 and 2. The basic design of the structure is shown in Figure 1. The structure included double-layered rebar in the ceiling and walls, rebar in the floor, a conventional lightning protection system with air terminals, interconnections, a ground ring electrode with ground rods, and grounded and surge protected AC power and signal lines. During the tests, a total of nine lightning flashes with thirty-eight return strokes

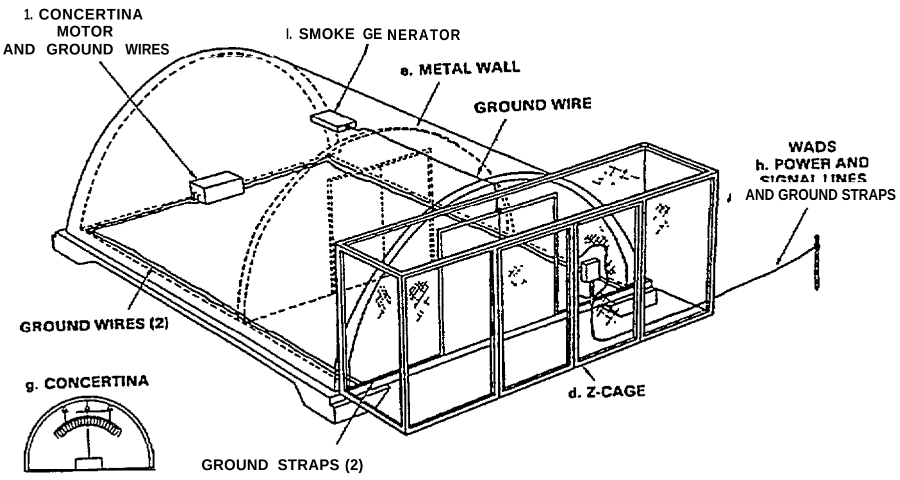

Figure 1. Basic Design Structure

were triggered to the structure. The average peak current of the return strokes was 12.2 kiloamperes with an average 0.3 microsecond risetime. Open-circuit voltages between exposed pieces of metal, short-circuit currents flowing on conductors connecting the metal pieces, the interior electric fields, and the internal magnetic fields were measured. In addition, current flowing at selected locations in the rebar and in elements of the lightning protection were measured. The results of the tests were surprising, in that they suggested that the only function of the air terminals and lightning protection system was to conduct the current from the lightning flash to the rebar, the lowest inductance return path to earth, which subsequently conducted the current to earth through the concrete and through large diameter conduits connecting power to the structure. Surprisingly, the testing showed that typically less than five percent of the lightning current flowed in the lightning protection system. Testing showed that the maximum voltage between exposed pieces of metal was 20 kilovolts with 1.9 kiloamperes short-circuit current when the results were extrapolated to an extreme one percentile (200 kiloampere) lightning strike. Subsequent interpolation of the data showed that the ground impedance played only a trival role in establishing the internal electromagnetic fields, voltages and currents. Interconnection of the wall and floor rebar, as well as grounding of metal penetrations to the rebar, were the dominant factors limiting the internal electromagnetic fields, voltages, and currents.

Rocket-Triggered Lightning Testing of Maintenance-and-Assembly Building

The results from the storage structure testing were surprising in that they suggested that the lightning protection system and maintenance of ground impedances of the lightning protection system played almost no role in determining the electromagnetic fields, voltages, and currents inside the structure, but that instead the topology and properties of the incomplete Faraday cage formed by the interconnected rebar determined the electrical response. Because of the differences between earth-covered structures and more conventional building construction, a decision was made to construct a building with a metal roof, rebar reinforced walls, and a rebar reinforced floor as shown in Figure 2. The building had

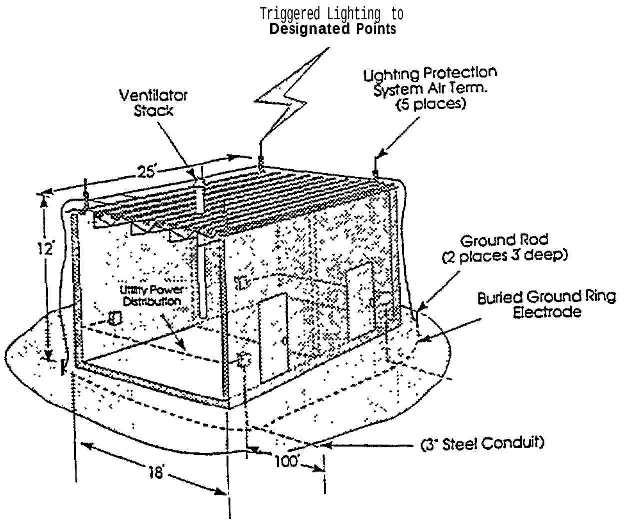

Figure 2.

a conventional lightning protection system with air terminals,down conductors, and a ground ring electrode with ground rods. The major unusual feature included in this building was an approximately l00-kilovolt dielectric breakdown barrier between the wall rebar and the floor rebar with connection points every sixteen inches which could be used to short out the dielectric barrier. The purpose of the barrier was to force as much current as possible to flow in the conventional lightning protection system to evaluate its effectiveness under the best possible conditions. The results of the 1994 testing of this building are detailed in Reference 3. In summary, even if the floor rebar was disconnected from the wall rebar, only about 40% of the initial return stroke current flowed in the conventional lightning protection system for several microseconds. Once arcs were established through the dielectric barrier or elsewhere in the first microsecond or so, virtually all of the remaining 100 microseconds of return stroke current flowed in metallic building structural elements. If the wall rebar was disconnected from the floor rebar, floor-to-ceiling voltages of approximately 200 kilovolts were measured. Almost all of the return stroke current flowed away from the building through two large diameter conduits intended to simulate part of an AC-power distribution network. If the floor rebar was connected to the wall rebar, floor-to-ceiling voltages of approximately 35 kilovolts were measured – comparable to voltages measured in the earth covered structures. Once again, both with and without the wall rebar connected to the floor rebar, the interior electromagnetic fields, voltages, and currents were basically unaffected by the presence or absence of a conventional lightning protection system.

In the 1995 testing of the structure, the two large diameter conduits were excavated and removed so that no metallic path went from the building to a large distance. The purpose of this change was to eliminate the major parallel path to the lightning protection system ground ring electrode and ground rods to force as much current as possible into the lightning-protection system. The results of these tests are detailed in Reference 4. Although more current flowed in the lightning protection system, over 30% of the current flowed in building structural elements, with or without connection of the floor rebar to the wall rebar. The interior floor-to-ceiling voltage remained at approximately 200 kilovolts if the wall rebar was disconnected from the floor rebar. The voltage had a strong resistive component, proportional to the return stroke current, in addition to the inductive component, proportional to the derivative of the return stroke current. Even in this very artificial case

Case Study of Lightning Effects on Modern Railway Wayside Signal and Control Systems

An example of how the knowledge gained from these tests affected evaluation of an electronic upgrade for a railway wayside signal and control system is now given. A recent upgrade from an electrical to an electronic signal and control system for wayside stations for a railway was found to be very sensitive to lightning attaching to the tracks or signal or AC wiring connected to the wayside stations. The upgrade included digital interfaces for signal and control, a stand-alone computer system, and a baseband radio communication system to eliminate point-to-point signal and control wiringField experience showed that lockups between the various subsystems occurred that were associated with thunderstorm activity. These lockups did not usually involve damage to the electronic equipment, but were extremely costly because the rail traffic was stopped until repair crews could come to the often remote site and complete the repairs. The repairs were completed so rapidly that identification of the lockup modes could not easily be accomplished after the event. When lightning strikes attached directly to the building or very nearby wiring, damage would often result to the equipment, but this happened sufficiently infrequently that the cost was considered acceptable. The lockups occurred sufficiently frequently, even from lightning attaching to tracks and wiring at substantial distance, that the cost was not considered acceptable.

A cursory examination of the wayside signal and control system showed that the rudimentary surge protection components and their associated high-inductance grounding system, complete with a single or dual ground rod system and often without even a rudimentary Faraday cage, could not easily be changed to prevent damage to the electronics from a direct lightning flash. Additionally, the review showed that the surge protection system could not be upgraded easily, mainly due to the lack of a Faraday cage, to prevent upsets from remote lightning. The approach to testing was to attempt to duplicate the lockups that occurred by injecting current pulses similar to those expected from remote lightning so that hardware/software responsibility for the lockups could be assigned to the appropriate subsystem subcontractor and corrected by hardware/software fixes. Testing revealed three different lockup modes involving hardware and software from all the major subcontractors. Several minor changes to grounding systems were suggested to improve their performance, but these changes were not expected to improve the performance of the system by more than 50%.

The root cause of the problem with this system was that the older electrical systems with slow acting surge protection were robust enough that lightning upset and damage was a minor problem, but when these systems were converted to modem electronics and telecommunications, lightning effects were not considered in the design. These problems could have been addressed trivially in the design and testing phase of the project.

Conclusions

Unless electromagnetic environments are considered seriously and, if necessary, mitigated early in the design phase of highly distributed intelligent transportation systems, the safety and reliability of these systems may be affected adversely, and costly and embarrassing upgrades may be required. Both testing techniques and computational tools are currently available to assess the effects of the environments of electromagnetic radiation, electrostatic discharge, and lightning on these systems.

Acknowledgment

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