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EVALUATION OF INTEGRATED COMMUNICATIONS AND CONTROL TECHNOLOGY FOR TRAFFIC OPERATIONS

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Final Report
TNW 98-07

EVALUATION OF INTEGRATED COMMUNICATIONS AND CONTROL TECHNOLOGY FOR TRAFFIC OPERATIONS

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16. Abstract

For traffic surveillance and control systems to function, an effective communications subsystem is required to transmit data from detector sites to a control center and to return control instructions to motorist information or control equipment. The primary goal of this research is to evaluate the cost effectiveness, flexibility, adaptability, and suitability of various communications media for collecting and transmitting information from and to detection and control sites. The specific objectives are to 1) evaluate the integrated communications and control for traffic operations and incident response 2) evaluate the cost-effectiveness and trade-offs of potential communication technology such as fiber optics, coaxial cable, and microwave systems for traffic control, and 3) assess the effectiveness of communication technology that is used on freeway in application for local jurisdictions. This report provides information intended for use by planners, designers, and construction managers in making decisions with regards to communication in traffic management and control systems.

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Table of Contents

List of Figures

List of Tables

Appendix

1.0 INTRODUCTION

1.1 PROBLEM PRESENTATION

The control of today's traffic calls for a fusion of time-honored communications media and the use of new technology – the practical and the theoretical. Two ingredients necessary for an adequate traffic control system are applied knowledge of the "normal" traffic stream, and the effective provision of a feed back mechanism which yields timely response of the stream's changing conditions. The solution of modern traffic congestion problems calls for increasing capacity through more construction and proper implementation of new and advanced communication technologies. The two necessary ingredients for a smoothly flowing traffic stream are a roadway with adequate capacity for "normal" traffic demand and a feedback mechanism allowing for response to changes in traffic stream conditions.

The major components (computer and peripherals, communications media and interface hardware, local control hardware and detectors) must work in unison with a high degree of reliability to obtain the maximum benefits and potential from a traffic control system. Of the major components, the communications media element of the network has the potential of being the most critical and expensive. Yet, it remains the least understood and often receives less attention than other control system elements. This report has been prepared as an update on data and information communications technologies applied to traffic surveillance and control.

1.2 PROJECT BACKGROUND

For traffic surveillance and control systems to function, an effective communications subsystem is required to transmit data from detector sites to a control center and to return control instructions to motorist information or control equipment. A communications subsystem that is effective, reliable, and cost effective is necessary for the traffic surveillance and control system to perform properly. The selection of the appropriate communication subsystem requires consideration of the performance characteristics and the cost trade-offs of the various communication media options.

The communications subsystem of a traffic surveillance and control system is a very expensive component. Its flexibility, reliability, adaptability, and expansion capability limit the level of performance and operational effectiveness of the entire freeway-control system. The cost, level of performance and effectiveness vary with the various communications media. Many communication technologies exist that can be used in this subsystem, including radio, twisted-pair cable, coaxial cable, fiber-optics cable, microwave, and laser technologies. The options of sole ownership or shared use also are available. There are also different configuration options for the communication subsystem. The design and development of the communication subsystem must select from among the numerous communications media to provide economic and effective transmission of traffic data and control signals, and effective integration with the detection and control technology to be used on the roadway. No single reference document is available that evaluates the cost effectiveness and analyzes the trade-offs of the various communication media. A recent report, "Communications in Traffic Control Systems" by FHWA, provides an assessment of existing and emerging communications technologies. (3) More recent studies have been undertaken by many state agencies and local jurisdictions.

1.3 GOALS OF THIS REPORT

The primary goal of this research is to evaluate the cost-effectiveness, flexibility, adaptability, and suitability of various communications media for collecting and transmitting information from and to detection and control sites. The specific objectives are to:

1. Evaluate the integrated communications and control for traffic operations and incident response
2. Evaluate the cost-effectiveness and trade-offs of potential communication technology such as fiber optics, coaxial cable, and microwave systems for traffic control
3. Assess the effectiveness of communications technology that is used on freeway in applications for local jurisdictions.

The state of the art of communications is rapidly and continually changing. Equipment and communications technology are constantly evolving. Costs are time and area dependent, consequently it is difficult to provide conclusive answers or standard designs. This report provides information intended for use by planners, designers and construction managers in making decisions with regards to communications in traffic management and control systems.

1.4 REPORT OVERVIEW

Information contained in this report stems form the following sources:

1. Review of applicable literature.

   For a detailed and thorough discussion on communication theory, "Traffic Systems Control Handbook" or "Computer Controlled Traffic Signal Systems", both by FHWA are recommended.

2. Contact with nationwide state departments of transportation.

   Questionnaires were sent to various state DOT's. With minimal response, it was found that existing systems in use are fairly consistent throughout the U.S.

This document is formatted in two sections. The first section shows an overview of communication theory followed by a presentation of the different media types used in traffic surveillance data communication. The equipment and theories as applied are then discussed in the fifth section in specific applications:

1. Small cities of about 200,000 population
2. Large urban highway networks of larger cities.

2.0 COMMUNICATIONS OVERVIEW

2.1 COMMUNICATION FUNDAMENTALS

It is necessary to understand the basics of electronic communication and how it is used in highway management, before discussing control system specifications and requirements. This section is presented to give a general understanding of the theories and terminology in the communications field. This section does not show why one transmission technique is better suited to traffic applications than another. It merely presents a basic explanation of the most commonly used communication formats and introduces the fundamentals of communication.

Communication is defined as the transfer of information from one place to another. A transmission link or channel is the path over which the information travels. This link may be a physical connection or an air-path.

A signal is transmitted over a link as electrical energy in the form of an analog sinusoidal wave which can be defined by the following parameters:

- wavelength – the distance between successive peaks of the energy wave, also known as period.
- frequency – the number of cycles per second measured in hertz (Hz), where 1 Hz equals 1 cycle per second.
- amplitude – the height or strength of the carrier wave.
- speed – speed varies with the transmission medium; in freespace the wave travels at the speed of light (300 million meters per second).

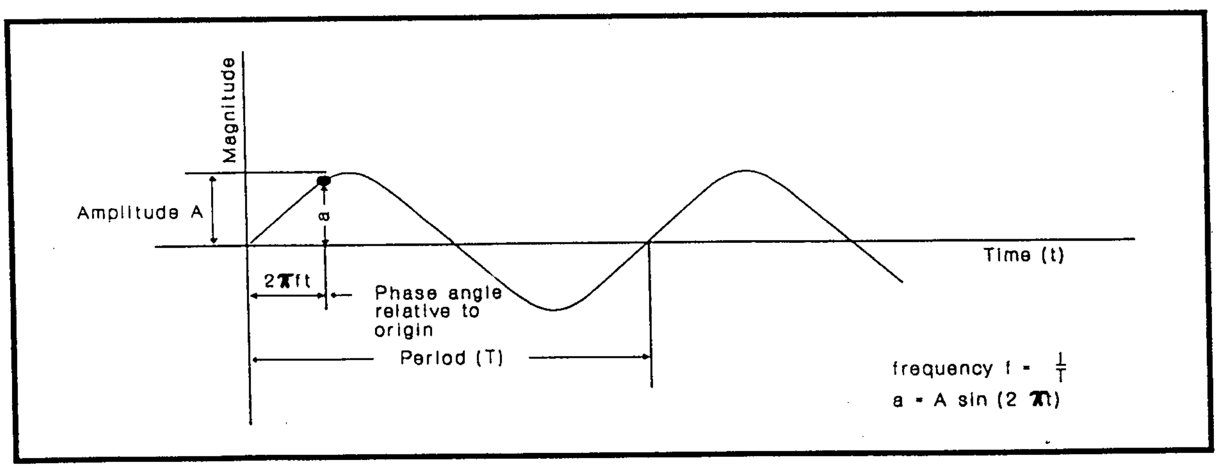

Figure 2.1 Analog Sinusoidal Wave

(Source: Reference 3)

Information for traffic control systems is digital and binary. That is, in most traffic applications, transmitted data takes 1 out of 2 possible values. Loop detectors detect the presence or absence of a vehicle. These systems are referred to as binary communication systems. In a binary system, a response such as presence of a vehicle is represented by a value of 1, whereas, the absence response is represented by a value of 0. Each single 2-valued unit of information is called a bit.

In digital communications, instead of having a continuous function (as in an analog sinusoidal wave), the information takes the form of numbers of one value or another (0 or 1 as in the case of a binary digit). An analog sinusoidal wave would be of the form shown in Figure 2.1 In comparison, a digital signal can be represented as the square wave form as shown in Figure 2.2.

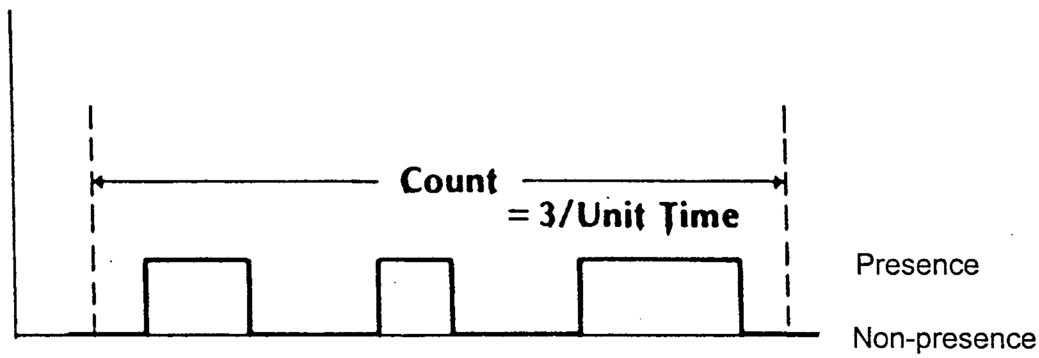

Figure 2.2 Digital Square Wave Form

(Source: Reference 3)

2.2 MODULATION

The traffic detector output signal is digital in nature, whereas, the transmission lines support analog sinusoidal waves for transmission. Therefore, in order to transmit along the link, the digital data output must be transformed or modulated into a sinusoidal analog wave. The analog wave is then sent through the channel to the receiving equipment. This sinusoidal wave must then be transferred or demodulated back to its original digital value so that it may be evaluated and appropriate actions taken. This process is called modulation/demodulation and is discussed in more detail following.

The device that transfers the information to/from a transmittable form is called a MOdulator/DEModulator or MODEM.

The available modulation techniques are now described:

2.2.1 Amplitude Modulation (AM)

Amplitude Modulation changes the strength of the carrier wave, using a signal of large amplitude to represent the 1 condition, and a signal of lesser amplitude to represent the 0 condition. Because the valid reception of an AM signal depends upon the measurement of the received signal strength, it is possible for line noise to degrade AM reception severely (e.g., static on a radio). For that reason AM is not often used in traffic control communication systems. See Figure 2.3 for a simplified graphic of amplitude modulation.

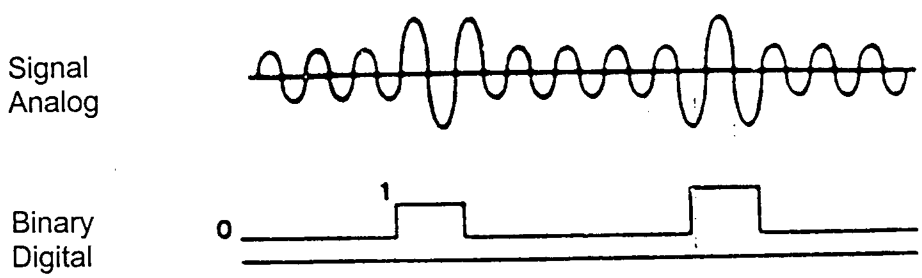

Figure 2.3 Amplitude Modulation Form
(Source: Reference 2)

2.2.2 Frequency Modulation (FM)

Frequency modulation uses a center frequency that is shifted to a higher frequency to represent one, and a lower frequency to represent a zero. When digital FM is used, only the two frequencies representing the 0 and 1 are transmitted as shown below. Digital FM is known as frequency shift keying (FSK). FSK is the most commonly used method for transmitting digital data in traffic control systems. See Figure 2.4 for a graphic of Frequency Modulation.

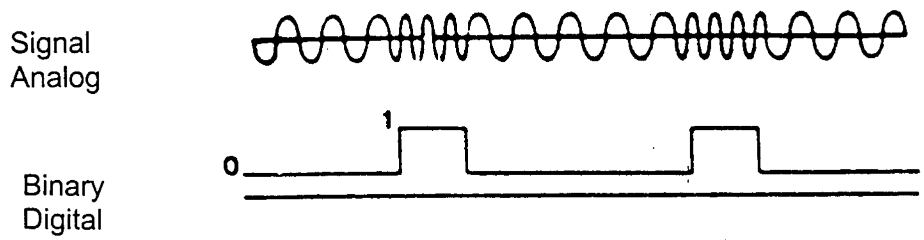

Figure 2.4 Frequency Modulation

(Source: Reference 2)

2.2.3 Phase Modulation (PM)

Phase modulation varies the phase of the carrier wave relative to a constant-phase reference signal. PM is known as phase shift keying (PSK) when used for digital communications. In a binary system, the phase is usually shifted 180 degrees (out of phase with the reference signal to represent a 1, but left unchanged (in phase) for a zero. See Figure 2.5 for a graphic representation of Phase Modulation. PSK requires rather sophisticated electronics to measure the transmitted signal precisely and the reference signal. PSK is often used for high-speed transmission.

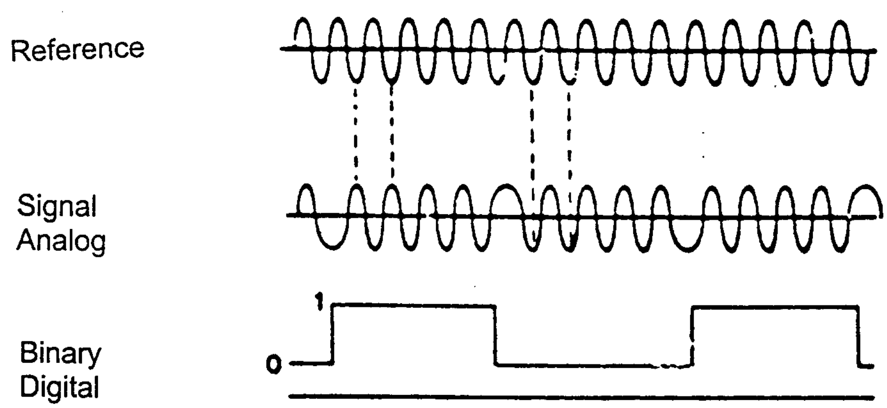

Figure 2.5 Phase Modulation

(Source: Reference 2)

2.3 MULTIPLEXING

A single facility or transmission path often is used to carry information simultaneously from several communication channels; this technique is referred to as multiplexing. The application of multiplexing techniques require an understanding of 'bit rate' and 'baud rate'.

Bit rate is the rate at which digital information is transmitted in bits per second. If a bit has a duration of 0.001 second as it is sent over a multiplexing facility, the bit rate would be 1000 bits per second. Some caution must be exercised in the magnitude of bit rate transmitted over a particular band width. The band width is the range of frequencies over which a signal can be sent without excessive attenuation and distortion. An excessively high bit rate results in a distorted and possibly uninterpretable signal, and the shorter the band width the greater the distortion. A practical guideline suggested in the FHWA Traffic Control Systems Handbook is that the bit rate should not exceed one-half of the available band width. (1)

All information or data that is sent over communication channels cannot be the traffic detector data or control information because the communications systems must use some of the bits for their operation, control and coding. The rate at which the bits useful to traffic control can be transmitted is known as the baud rate.

In a multiplexing example of two detectors, the system would appear as shown in Figure 2.6.

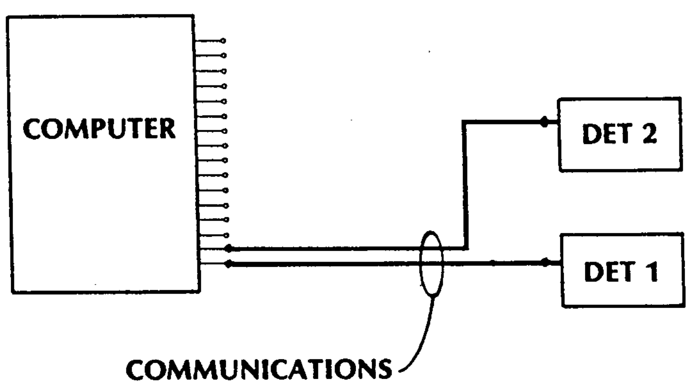

Figure 2.6 Two-Line Communications Subsystem with Two Detector Input
(Source: Reference 8)

This is a 2 line communication system with 2 bits of the 16 bit computer input word being used. The computer would read presence or non-presence at each detector as follows:

Detector A	Detector B	Input Word
No presence	No presence	0000000000000000
Presence	No presence	0000000000000010
No presence	Presence	0000000000000001
Presence	Presence	0000000000000011

This approach has the limitation of the number of detectors to the number of bits in the computer input word. In this example, no more than 16 detectors per computer are allowed. When there are more than 16 detectors, additional equipment is necessary. In this example, one line is required for each detector. In large systems with hundreds of detectors it is evident that this given example is impractical.

At this point it becomes useful to examine possible techniques for reducing the number of lines required to communicate between the computer and detectors or between the central controller and the field. A single line can be used between detectors and the central computer with the use of modulating techniques as discussed previously. This system can be represented as shown in Figure 2.7 below, where the multiplexing process translates the detector data into frequencies that can be transmitted, and then recode it to feed it into the computer.

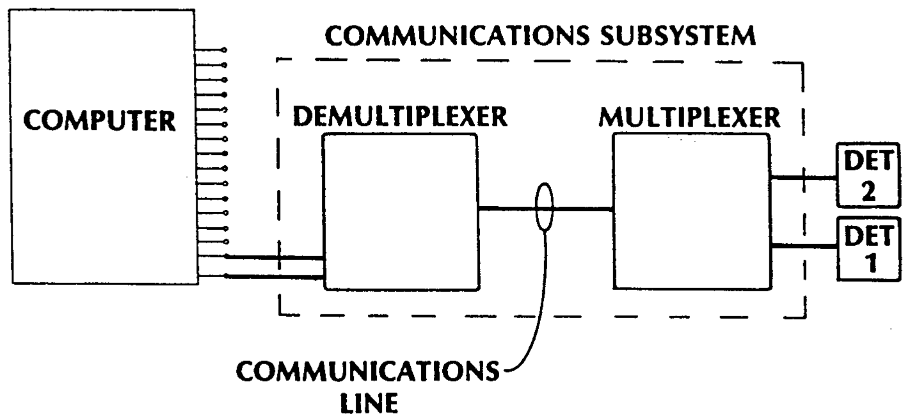

Figure 2.7 Total System Configuration

(Source: Reference 8)

To address the problem of limited number of input devices, a computer interface unit CIU is used. As a part of its interface, the computer has three basic groups of lines: 16 input lines, 16 output lines, and a group of device and address lines. Data transmission lines in a computer are known as a bus. These line groups are therefore referred to as an input bus, an output bus and an address bus. The CIU is added to the system from the previous example as shown in Figure 2.8.

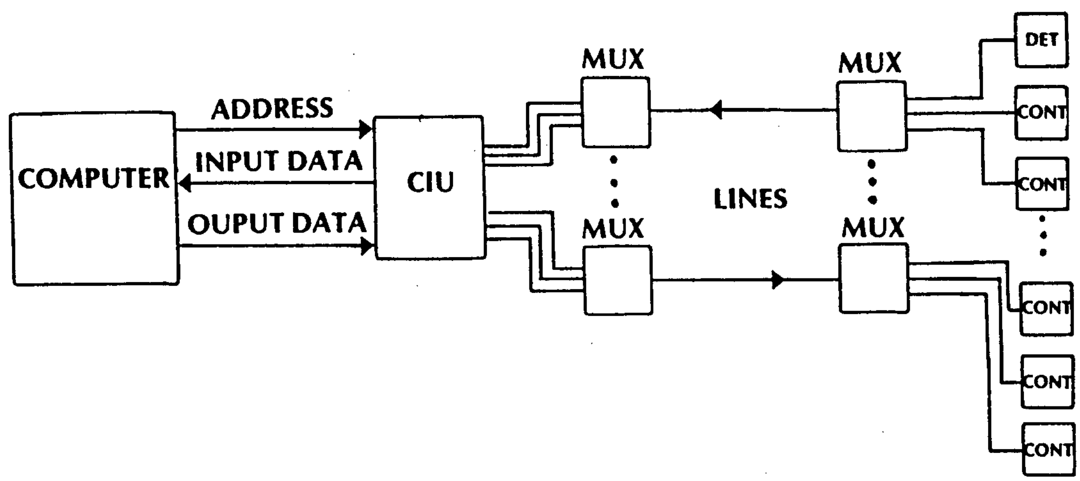

Figure 2.8 Two-Way Communications
(Source: Reference 8)

The address bus is used to tell the CIU via binary code, which group of lines or detectors to access. Then, the input bus accepts information from the detectors. The discussion thus far has only considered traffic detectors. However, other devices such as traffic signal controllers or variable message signs, could receive information and are implemented in the example system just as the detectors are. The output bus sends inforrmation to the controller. Output information to a traffic controller could include advance pulse to send the traffic signal into the next phase, that is, shut off a red light and sequentially turn on the green light.

2.3.1 Frequency Division Multiplexing

The multiplexing technique translates different detector outputs into different frequencies. In the two detector examples discussed previously, the detectors would determine presence or no presence as shown in Figure 2.9 and the modulator would convert the presence signals into different frequencies.

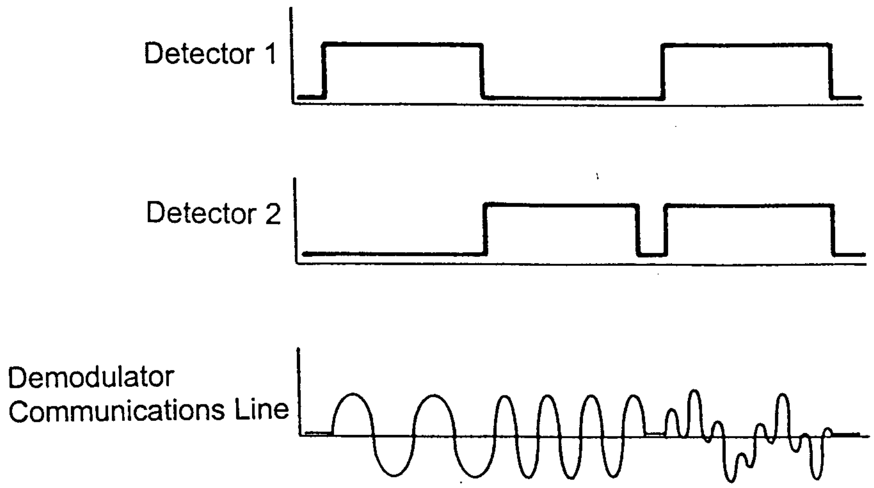

Figure 2.9 Signal Being Transmitted for Detectors Inputs

(Source: Reference 8)

This is very similar to the device used on push button phones. Each button on the phone keypad, when depressed, causes the generation of an unique tone. A high tone is the result of transmitting a high frequency whereas a low tone is the result of transmitting a low frequency. In other words, this scheme varies the transmitted signal frequency to represent different signal values.

This is known as frequency shift keying which is applied to digital communication. In our binary transmissions system example, the presence signal would generate a signal of a particular frequency while a non-presence signal would generate another frequency. No signal could be used in the instance of no presence, however the system could not determine detector failure. Because the lack of signal associated with a failed detector is synonymous with a no presence indication, the computer could misinterpret a broken detector as a non-presence indication. Therefore, each detector has two frequencies associated with it.

This technique, frequency division multiplexing (FDM), can be seen to reduce the number of required communication lines between the field and the central computer. In sum, in the FDM technique, the communications system is composed of transmitting devices connected to modulators which are in turn connected to the communications line. The transmitting device (detectors) is continuously sending one of two possible frequencies. This is the basic characteristic of FDM, each modulator is continuously transmitting information at different frequencies and the demodulators are continuously receiving transmitted information.

2.3.2 Time Division Multiplexing

Another available technique is time division multiplexing (TDM). With this technique, peripheral devices (detectors, actuators, controllers) time share the communications line. An example of such a system for detectors is shown in Figure 2.10.

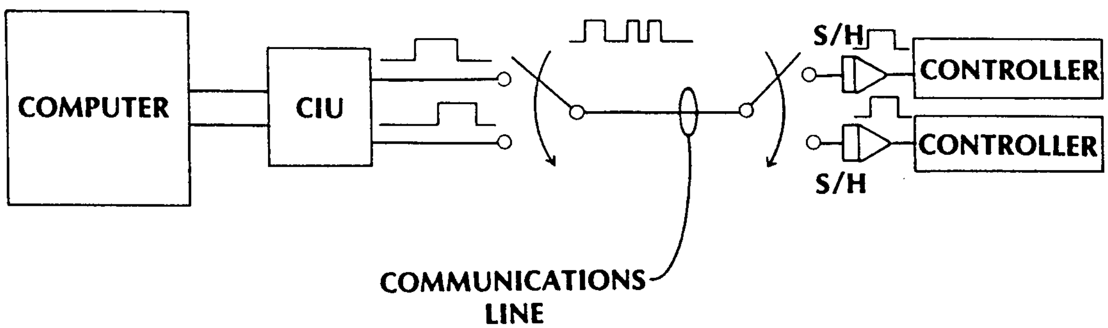

Figure 2.10 Advance Pulse Transmitted to Signal Controllers from Computer through CIU Using TDM (Source: Reference 8)

This system is represented schematically as a switch which rotates to each CIU output for an allotted amount of time. A sample and hold unit, a buffer, collects the data during each full rotation to be sent on the next rotation. And then, proceeds on to the next output.

2.4 ATTENUATION

The signal deteriorates as it travels along the communications channel for many reasons. As travel distance increases, the signal becomes weaker which is known as attenuation. At times, the attenuation is measured as a ratio of the received signal strength to the transmitted signal strength. This is measured on the log base 10 scale in decibel units. The loss in signal strength can be improved by placing repeater amplifiers into the line to amplify the signal strength back to an acceptable level. This obviously adds to the cost of communications. Attenuation is relatively less if the signal is within the band width of the communication media. Figure 2.11 shows the attenuation with respect to frequency for various media.

2.5 NOISE

Unwanted signals, referred to as noise, may become introduced to the signal from external sources such as lightening. This noise can become so great that the signal is masked by the noise or static, and the signal cannot be interpreted at the receiver. The likelihood for noise increases as the communication distance increases.

2.6 INTERFERENCE

Interference is a disturbance to the signal caused by electronic means. One source is a signal from another communications channel in the same electrical system, such as cross-talk, which is the electrical field interaction between two parallel lines operating at comparable frequencies. The twisted-pair cable reduces this interference because the same current is flowing the opposite direction in each wire, thus the generated electrical field from the two wires acts in the opposing direction to each other and cancels out.

Interference can also be generated from an unrelated source, such as a radio frequency from other transmitters (3). Electronic phenomenon such as echoes also create interference.

2.7 TRAFFIC APPLICATIONS SUMMARY

Multiplexing techniques have been discussed in this section. Basically, these techniques can be thought of as different hardware system design setups or as different routes that information can take in getting from one place to another. In transmitting information, the data can take different forms.

Frequency Division Multiplexing, the most common form of multiplexing used in traffic surveillance, utilizes two different frequencies for each data source- one frequency for presence detection and another frequency for non-presence detection. Digital Frequency Multiplexing is known as frequency shift keying (FSK). This technique typically uses a centered frequency around which the presence and non-presence frequencies are centered. Typical frequencies for a two FSK system operating over a voice-grade line are presence equal to 2500 Hz and non-presence equal to 500 Hz. The

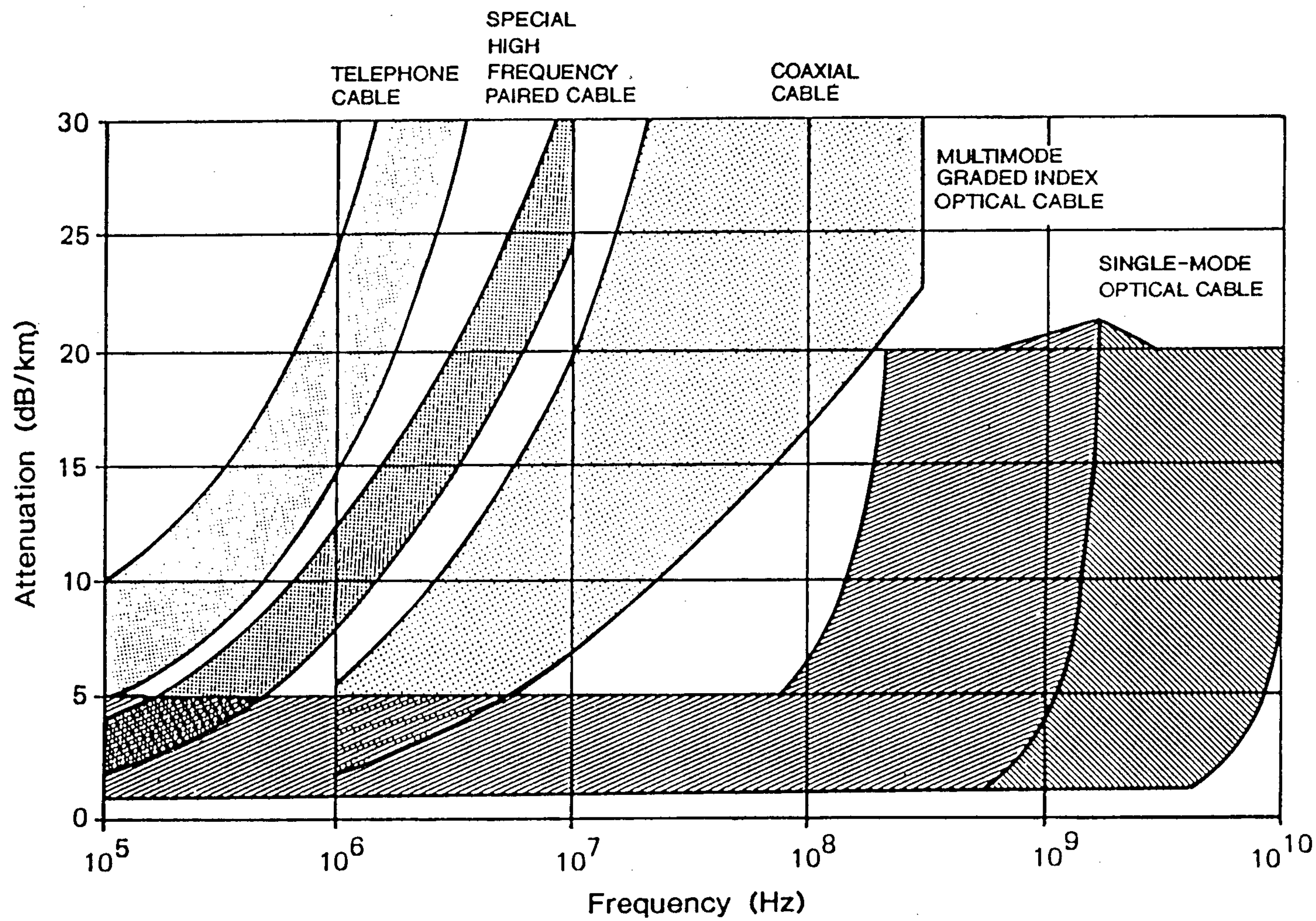

Figure 2.11 Attenuation Versus Frequency (Source: Reference 3)

spacing between these two frequencies gives a good approximation of an upper limit on the number of bits-per-second (the highest transmitted bit rate) that can be used with the given FSK-signaling frequencies. This limitation on transmitted bit rate assures that the receiver has enough time during the duration of each transmitted bit to differentiate adequately between the various frequencies that may be transmitted. In practice, many systems operate well below this maximum, thereby decreasing the probability of improperly identifying the received frequency and obtaining erroneous data. With the example given earlier, the deviation would be 2500-500 = 2000 Hz, allowing 2000 bits per second as the recommended maximum transmission rate.

The idle condition, for instance during peak hour when signal actuators are not used and a preset signal timing plan is instituted, is handled by transmitting the central frequency (1500 Hz in our example). That way the computers are able to detect that the actuator is still functional and differentiate between an equipment breakdown (no frequency received) and the case of actuator no-implementation (1500 Hz being received).

3.0 SYSTEM COMPONENTS

3.1 BASIC NETWORK CONFIGURATION

The basic traffic control system is composed of equipment in the field communicating with surveillance equipment/displays in a control center. The central controller or control center communicates with the field equipment to provide real time control of the traffic flow. In the example of a traffic incident the incident would be verified by CCTV, and the control from central control would be in the form of controls exercised on the surveillance video camera. Upon verification, the operator at central control would then notify appropriate incident response personnel - maintenance, fire station, police, ambulance, etc. This two-way communication between the field and central control is called duplex control where there is communication between the field equipment and centralized control. Another example would be the case of traffic flow monitoring. Upon detecting heavy demand on a freeway on-ramp, for instance, the operator at the central control center could then adjust the ramp meter signal timing to better accommodate the sudden peak of traffic demand, and remedy traffic flow both on the freeway and on the surface streets connecting with the freeway.

The traffic control network configuration can take one of two basic configurations; centralized network and distributed network. For a graphical representation of the network configurations refer to the diagrams shown as Figures 3.1 and 3.2.

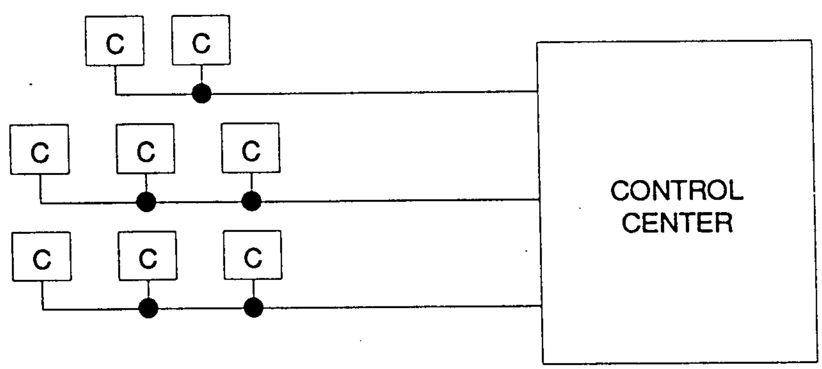

Figure 3.1 Centralized Network

(Source: Reference 3)

In a centralized network, every piece of field equipment communicates directly with the central computer in the central control center. Drawbacks of this type of system include:

1. With long cable runs (greater than about 5 miles) extensive signal amplification is required. Because each piece of equipment is communicating on it's own dedicated line, that would require amplifiers for each line.
2. Built-in redundancy to prevent the equipment from becoming uncommunicatable in the event of line failure would then require running additional lines to each field unit, individually.

Advantages include:

1. When there is single line failure, only one piece of equipment is affected, not the whole network of equipment.
2. Trunk lines must provide adequate capacity for the communication needs of all devices along the cable route.

The distributed network scheme consists of trunk lines being routed to distribution points, or hubs. A multiplexing-demultiplexing device is located at each hub that distributes the trunk communication signals to the individual devices. The distributed network scheme can be of many levels. Such as, a central computer communicating through trunk lines to the first level of hubs, which then further branch off to other hubs which than could branch off to the field equipment.

Disadvantages include:

1. When there is a single trunk line failure, every piece of field equipment goes down with it.

Advantages of this type of system configuration include the following:

1. Built in redundancy to prevent the communication failure between the central computer and field equipment, would involve running a single adjacent trunk line.
2. Reduced data load along the trunk facility due to the multiplexing capabilities at the hubs.

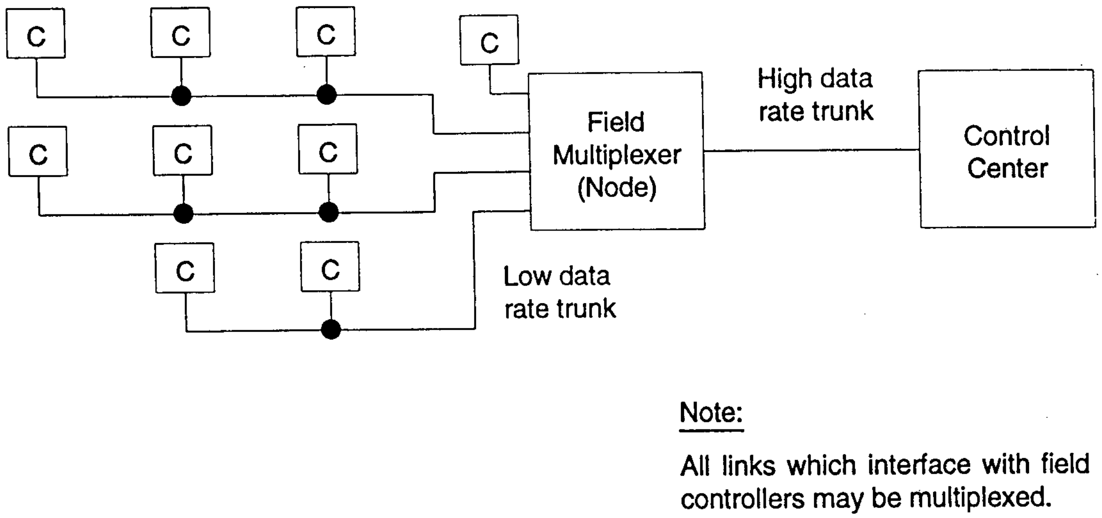

Figure 3.2 Distributed Network

(Source: Reference 3)

This section introduces some of the hardware and equipment to be used and implemented in some typical designs to be presented later. The equipment is divided into four categories: 1. Detectors, 2. Controllers, 3. Transmission media, 4. Miscellaneous supporting equipment.

3.2 DETECTORS

Detectors are comprised of three primary components: the sensor, the lead-in cable, and the interpreter/receiver. Detectors are used to derive volume, vehicle speed, lane occupancy, queue lengths, and to infer congestion, incidents, stops and delays. Following is a description of the many different types of traffic presence detectors:

3.2.1 Inductive Loop Detectors

Theory - The inductive loop detector consists of one or more loops of insulated wire placed in saw cuts in the pavement, with a lead-in cable connecting the loop to a detector electronic unit which registers the presence or non presence of a vehicle. To detect the presence of a vehicle, the detector electronic unit sends an A.C. current, typically in the range of 20 to 200 kHz, though the loop placed in the pavement. The loop and lead-in wire process a combination of resistance, inductance, and capacitance.

This loop system forms a tuned electrical circuit where the wire loop is an inductive element. As a vehicle passes over or is stopped over the loop, the inductance of the loop is decreased. The detector measures and checks for inductance fluctuation. The decrease in inductance due to the passage of a vehicle signifies the presence of the vehicle to the detector which in turn signals the controller of such detection.

Typical Use - vehicle presence/non-presence indication

3.2.2 Magnetometer

Theory - Flux lines in the vicinity of a vehicle bend in order to pass through it because a ferrous vehicle is more permeable to the lines of the Earth's magnetic field than air is. The concentration of flux is known as the vehicle's magnetic shadow. The magnetic shadow consists of increased flux below and above the vehicle, and decreased flux below it. Instead of registering fluctuations in an inductive field generated by the loop, the magnetometer detects the increased flux below the vehicle.

Typical Use – In pavement type of vehicle detector

3.2.3 Magnetic

Theory – A coil of wire with a highly permeable core is placed below the roadway surface. When a ferrous object passes over the coil, the constant lines of flux passing through the coil are deflected by the vehicle, thus causing voltage to be induced in the coil. A high-gain amplifier then enables this voltage to operate a relay, which sends a message regarding this change in voltage, indicating the presence of a vehicle.

Typical Use - In pavement type of vehicle detector.

3.2.4 Video Cameras

Theory – Video cameras offer two methods for detecting traffic presence.

Closed circuit television – offers control personnel a direct viewing of the traffic flow.

Video image processing – automatic vehicle presence detection can be achieved with the use of a computer measuring changes in intensity level of the image. The user electronically draws "detectors" on the video screen. For a base value the computer determines the intensity level of the marker. Measuring any changes in the intensity level of the "detector" are interpreted as vehicle detection or presence. Computer algorithms differentiate between vehicle detection and false images such as shadows, changing lighting conditions, or glare. Current state-of-the-art video imaging technology provides a capability to 'track' images to assure they are vehicles.

Typical Use – Two different types of detection are possible with video surveillance. As described above, presence can be detected as vehicles move across video detectors. Motion and direction can also be determined by tracking a vehicle video image as it travels through the image.

3.2.5 Ultrasonic

Theory – Similar in nature to sonar used in underwater submarine navigation, the sonar detector emits pulses of ultrasonic energy. An ultrasonic receiver measures the travel time of the energy between emitter and receiver. The time elapsed between the burst transmission and the echo reception is measured. A base time is established for vehicle no presence such as the reflection time from emitter to pavement and reflection back to the receiver. When a vehicle enters the path of the emitted energy pulse, the time of reflection decreases as the distance from emitter to reflector decreases.

Typical Use – Ultrasonic detectors are above ground detectors located either overhead or at the side of the road. When mounted at the roadside, lane specific information cannot be attained. Can be used for both passage and presence.

3.2.6 Radar

Theory – Radar detectors operate on the Doppler principal. Similar in method to the ultrasonic detector, Radar detectors check for reflection of emitted pulses of energy. When a vehicle enters the transmission path, the energy waves are reflected at a different frequency. When this frequency change occurs, the detector signals the presence of a vehicle.

Typical Use - Because Radar detectors operate on the Doppler principal, only vehicles in motion will trigger the detector. Therefore, these detectors can only be used for passage or motion not for presence detection.

3.2.7 Infrared

Theory – Infrared vehicle detectors also operate on the Doppler principal. An emitter and a receiver are necessary equipment for detection using energy waves in the infrared spectrum. The receiver detects vehicle induced changes in the returning energy waves. Proper vehicle detection using infrared energy is vulnerable under the following conditions:

- Changes in light intensity and weather causes the emitted beam to scatter
- Environmental conditions – dirt, ice, or snow will impair detection.

Typical Use – Siting of infrared detectors has been a problem, since the vehicle must interrupt the infrared light beam.

3.3 MOTORIST INFORMATION AND CONTROL EQUIPMENT

Traffic control systems are comprised of traffic controllers and driver information systems. Traffic controllers can operate independently to control intersections or ramps or maybe coordinated with other intersections on the arterial or system wide.

3.3.1 Type 170/179 Controllers

Type 170 controllers are manufactured according to the specification jointly developed by the New York and California Departments of Transportation. Since that time, NYDOT has developed the Model 179 Controller.

The Model 170 Controller is based on the conceptual approach of hardware standardization. The controller assembly is a package consisting of standardized modules and wiring harnesses all housed in a standard cabinet. The fundamental approach of this type of controller is to provide the hardware to control many types of devices specified by the user. It is an attempt to develop one controller capable of meeting any existing or future traffic needs at local intersections. The type 170 controller responds to new traffic control conditions through software updates. Control is implemented by computer software. Therefore, this type of controller can be tailored to the desires of the individual user by developing appropriate computer software.

Available software programs for the Model 170 Controller unit include:

- Semiactuated and full-actuated control
- Pretimed (fixed time) control
- Ramp metering control
- Grid and arterial master control
- Diamond interchange control

3.3.2 Type 2070 Controller

The new Model 2070 controller unit is more versatile, and is likely to replace the 170 and 179 controllers very soon. Caltrans initiated their development. Many highway agencies are now developing specifications for use of the 2070's. Software for effective programming and general use of these controllers is presently under development.

3.3.3 NEMA Controllers

Controllers of this type are manufactured according to specifications developed by the National Electrical Manufacturers Association (NEMA). The standards cover:

- Definitions for functions and hardware
- Environmental requirements and test procedures
- Interface requirements
- Physical and functional requirements
- Peripheral equipment to complete the controller assembly, such as load switches, conflict monitor, detector amplifiers, flasher switches, electrical terminals and facilities, and power supply

NEMA controllers are developed and manufactured on the basis of function standardization.

3.3.4 Changeable Message Signs

Changeable message signs display alphanumeric information that can be updated or changed on a real-time basis. The visual word, number, or symbolic display can be electronically or mechanically varied as traffic conditions warrant. The central control center typically sends the alphanumeric message or codes to select preprogrammed messages.

The changeable message signs typically require half-duplex control. This allows traffic surveillance personnel to send commands to change the display as well as receive information regarding the message currently displayed.

3.3.5 Highway Advisory Radio (HAR)

Through the use of a local radio broadcast, Highway Advisory Radio essentially provides a means for conveying real-time highway and traffic-related messages to the driver with the use of an in-vehicle AM radio receiver. The service is typically provided at either end of the AM band, 530 or 1610 kHz. This form of motorist information and control is unique in that the control communications go directly to the driver, not to a medium that controls the driver.

The HAR system consists of a low-powered AM transmitter broadcasting through either a vertical monopole antenna or an induction cable antenna.

Monopole antennas offer the following advantages/disadvantages:

- Size – they are physically small and can be installed in a relatively small space
- Installation effort – they can be installed in a short period of time in a variety of environments (over bare earth or pavement, on buildings, etc.)
- Visibility – pole antennas are visible
- Relocation – they can be easily relocated
- Cost – Usually less costly to purchase and install versus a cable antenna
- Area of Coverage – circular coverage zone which may interfere with coverage zones on adjacent highways
- Damage – Subject to damage by weather, accident, or vandalism

Induction cable antenna systems offer the following advantages/disadvantages:

- Installation – the cable can be placed above ground or below ground
- Damage – If installed below ground, the cable is not subject to damage by weather nor vandalism.
- Cost – If installed below ground, it is more costly to purchase, install, and relocate
- Visibility – If installed below ground, it is virtually invisible
- Continuous coverage – coverage is possible through tunnels, in buildings, under overpasses.
- Area of coverage – the radiation zone is confined to within 100 ft or less from the cable, and thus minimizes interference with nearby coverage zones.

Two types of data transmission are required for Highway Advisory Radio:

- Voice transmission to the field transmitter
- Control signals to the transmitter and road way sign flasher indicating the broadcast availability.

3.4 COMMUNICATIONS MEDIA

The following discussion centers around the available and most widely used communications media, that is, the hardware forming the data transmission path. The path can take one of two forms: hardwire (twisted wire pairs, coaxial cable, fiber optic cable) or an air-path (satellite, radio, microwave, laser). Another option for communications is the shared use or leased lines; telephone and cable TV companies have the facilities, unused capacity and service to provide communications for traffic data.

3.4.1 Twisted Wire Pairs

This is the most widely used communications media in traffic control. Physically, twisted wire pairs are composed of individual insulated copper wires twisted together into pairs to minimize the effect of induced currents. Because twisted wire pairs always run directly adjacent to each other, any induced signal from an interference source has the same effect on each of the conductors. At the receiving end, only a difference in voltage between the two conductors is being measured. The induced voltage is the same in each conductor and therefore is not noticed.

Another characteristic of twisted wire pairs is reduced interference known as cross talk between adjacent pairs. As previously stated, the same current flows in opposite directions through each of the conductors. Accordingly, the radiated electric fields are in radially opposite directions which causes the fields to counteract each other.

When used for data transmission, the twisted-pair cable is usually of the voice-grade type with usable bandwidth ranges from 300 Hz to 3,000 Hz, the audible frequency range of the human voice. This communications media typically employs 1200 baud frequency shift keying (FSK) modems.

The advantages of twisted wire pairs include:

- It is a well established and well understood technology
- It is very flexible
- It eliminates 'cross talk' interference

The disadvantages are primarily due to the fact that this is a mature technology, consequently;

- It has high construction costs
- It is susceptible to noise and interference from numerous sources
- Maintenance and repair costs can be high

3.4.2 Coaxial Cable

Coaxial cable consists of a center conductor composed of copper clad aluminum. This center conductor is surrounded by a dielectric which is either solid foamed polyethylene or a gas. This is surrounded by an exterior protection jacket consisting of low density, high molecular weight polyethylene. Coaxial cable typically has a very wide radio-frequency bandwidth between 5 MHz to 550 MHz. With this large frequency range, coaxial cable can accommodate many television channels.

A coaxial cable system employs frequency-division multiplexing (FDM) and time-division multiplexing (TDM) which can simultaneously accommodate data transmission from many sources and of many types (data, voice, television).

The advantages of coaxial cable are:

- It is a sound, well understood technology
- The cable is relatively free of noise and interference

The disadvantages:

- It has relatively high construction costs
- Connections and splices can be troublesome from noise or moisture
- The required expertise of technicians and test equipment is higher than for twisted wire

3.4.3 Fiber Optic Cable

Fiber optic cable can be thought of as a cylindrical optical waveguide. Fiber optic cable consists of a center glass or plastic core surrounded by a higher loss, lower refractive cladding layer. Because of the difference in refractive indices, light waves which strike the cladding layer below the critical angle of incidence are reflected back into the core section. In essence, light waves are transmitted through the center glass fiber reflecting off the wall so that the waves travel along the inside of the fiber until reaching the end of the transmission line.

Light rays that reflect at the same angle are referred to as propagating in the same mode. A mode represents a path which a light ray may follow along the fiber. The number of modes present in any fiber optic cable is controlled by the cable core diameter. As diameter increases, the number of modes increase. Multi-mode fiber supports several modes of propagation. Whereas, optical fibers that are of sufficiently small diameter with the appropriate refractive index support only a single mode of propagation and are appropriately called single mode fibers.

There are two types of multi-mode fibers: step index and graded index. Step index multi-mode fibers are characterized by large differences in the refractive indices of the core and the cladding layer. Dispersion can be described as the broadening of the light pulse as it travels along the fiber. The light pulse can spread such that the trailing portions of one pulse arrive at the receiver after the leading portions of the next pulse. With this type of interference, the receiver is not able to distinguish between individual pulses. Different longitudinal velocities of propagation associated with different path lengths in this type of fiber cause signal dispersion. Accordingly, the step index, multi-mode fiber is only appropriate for data transfer over short distances and reduced transmission rates.

Graded-index multimode fiber is characterized by a gradual change in refractive index from the core center to the outside of the cladding. The refractive index is highest on the fiber core and lowest at the core-cladding interface. Because light travels more slowly along the denser core, waves traveling different path lengths travel at approximately the same longitudinal speed. This results in reduced dispersion caused by multimode travel. Consequently, graded index, multimode fiber is appropriate for much longer distances at higher transmission rates.

Fiber optic technology allows for data transmission at very fast rates of wide bandwidths over long distances without amplification, on the order of one mile for multi-mode fibers and up to 50 miles for single mode fibers. Because of the high capacity, high speed transfer rates, optical fiber cable is best suited for trunk lines carrying information from many detectors through hubs to and from the control center.

The advantages of the fiber optics cable are numerous; they include:

- Large capacity
- They are immune to noise
- They are small and light
- The fiber optic cable can be installed in conduit, buried or overhead
- Data transmission rates are high

The disadvantages for this media include:

- Sophisticated technology, requiring well trained technicians
- Construction costs are high

3.4.4 Cellular

The use of cellular telephones to transfer data uses the telephone network involving the use of radio waves. The connection with the use of cellular technology has proven to be the weak link of this system with the following drawbacks:

- Radio waves associated with cellular telephones have proven to be very susceptible to interference due to weather conditions, external electromagnetic interference and other noises
- Very limited bandwidths are available per channel, making it impossible for video transmission
- Very poor noise to signal performance, making it unreliable as a means of data transmission
- Operational costs can be prohibitive for a system with continuous poling due to the reliance on a commercial provider

Any advantages cellular communication offers, the same advantages can be attained by leasing telephone line at a lower cost.

The advantages of cellular radio include: (3)

- Cost effective for infrequent communications
- Eliminates land line or connection to telephone
- Useful for temporary installations
- Modems are readily available
- Network covers 93% of US population

The disadvantages of cellular radio are: (3)

- Airtime costs are excessive for continuous communications
- Limited service providers per area
- Actual data that can be sent is reduced by protocol overhead
- Service may not be available in remote areas

3.4.5 Spread Spectrum Radio

Spread spectrum communications systems spread the transmitted signal over a very wide bandwidth. This offers two important technological advantages over conventional transmission schemes. First, the spreading reduces the power density of the signal at the frequency within the transmitted bandwidth, thereby reducing the probability of causing interference to other signals occupying the same spectrum. Second, the signal processing in spread spectrum systems tends to suppress undesired signals, thereby enabling such systems to tolerate strong interfering signals. This results in significantly higher signal to noise ratios than can be achieved by conventional techniques such as AM that use no bandwidth spreading.

Features –

- No FCC license required
- High immunity to interference and jamming
- Range to 20 miles (line of sight)
- Selectable transmit/receive channels
- Selectable data rates
- Programmable power output
- Numerous communications channels available by combined selection of frequency & P/N code

The advantages of spread spectrum radio are quite numerous: (3)

- Very flexible
- FCC does not have to provide approval
- Works well in a high noise area
- Presently in use in industrial applications
- Requires low power
- Can be used in an integrated hard-wired and radio system
- Low initial equipment and construction costs

The disadvantages are for spread spectrum radio are:

- It is new, untried
- Range depends on local topography
- Higher band width than fixed frequency radios
- Requires external antennae and cable
- Requires high level expertise for technicians and sophisticated equipment
- Unprotected channel space

3.4.6 Microwave

Microwave signals travel through the atmosphere along a line-of-sight path between antenna transceivers. This format allows for full-duplex data transmission. Licensing with the Federal Communications Commission (FCC) is required. When landlines are not possible or feasible, as at waterways or ravines, or when transmission is required across barriers, such as railway lines, bridges, or large vacant areas, microwave transmission may be an attractive option.

Data transmission with this media requires a microwave emitter and a receiver. Additional requirements for microwave transmission include a structure on which the antennae hardware can be mounted, and conduit to controller cabinets.

The advantages of the terrestrial microwave links include: (3)

- High capacity point to point trunk service
- Traffic data and a few video channels can be transmitted
- Can transmit traffic control protocol
- Can handle both analog and digital signals

The disadvantages of microwave are: (3)

- It requires line-of-sight path
- Usually requires FCC license
- Only limited availability of channels
- Operating frequency may be dictated
- Atmospheric conditions may interfere with transmission
- Unsightly antennae tower may be needed
- Restricted available band width

3.4.7 Laser

This technology is in the evolving stages. Light energy very near the infrared frequencies is used to transmit data through an air-path. It has been used in a traffic control communication system with single or multiple optical transmission diodes and light-sensitive reception diodes directed at their counterpart at adjacent intersections. A data processing capability or microcomputer is required at each site.

The limitations on the system include:

- No deflection or movement in the optical heads is permitted
- Their range of 3000 ft. with high-powered injection laser diodes
- Heavy fog or other severe weather conditions can limit their effectiveness, though normally weather conditions have little effect
- A clear line of sight must be maintained
- At peak power, eye safety standards must be met

This medium has potential for only limited applications due to its' relative cost, and firm technical requirements.

3.4.8 Owned vs. Leased

Many traffic control system lease service from telephone companies or cable TV companies. There are major benefits in leasing the service, in that a high quality, redundant communication network can be accessed at low initial connect costs. The design is flexible, and can be readily adapted as time requires. In addition to the lower initial construction costs, the maintenance costs are low, and maintenance staff requirements are few.

Some other advantages of leasing include:

- System is already in place and is very comprehensive
- System can provide ready access virtually anywhere
- System provides redundant service for emergencies and natural disasters
- Maintenance costs are low
- Agencies personnel are relieved from the responsibility of repair of the communications system after a natural disaster

The disadvantages are often the reasons that jurisdictions elect not to use this alternative. They include:

- Lease fees could change
- The jurisdiction doesn't have control on when and how maintenance and repair is undertaken so maintenance response is slow.
- Video channels take up most available band width
- Unreliable leased line service
- Frequencies of available channels are least desirable, due to their susceptibility to noise and interference
- Area of network coverage and layout may not coincide with traffic signal system locations
- Service is not a priority with the providers so cooperation and commitment to the service may not be present.

3.4.8.1 Telephone Company Service

A number of studies have shown that lease telephone lines are the best option when all factors are taken into account (3, 18, 20). Local area regulations or constraints majorly impact the decision. The lease changes vary widely. For example, non-recurring charges range from $110 to $358 with a monthly charge from $10.89 to $38, with 2 channels per circuit; other interoffice channels and equipment costs are not included. (3)

Typically, for voice grade lines, the charges included a one-time charge to install the private channel, a monthly charge for each of the terminators, a monthly charge based on airline miles, and an optional features charge.

Digital line service provides communications between traffic control centers. Voice grade lines often carry the data from the field to the traffic control centers.

3.4.8.2 Cable TV Service

The use of cable TV leased service provides a shared use coaxial system. However, a firm franchise agreement is needed that permits use of the system for traffic control. The quality of the video signal required by CATV are less than that provided for traffic data transmission.

The location of CATV service is primarily in residential areas. Service to the Central Business District or industrial areas may be limited, if available at all.

3.5 SUPPORTING EQUIPMENT

3.5.1 Amplifiers

An amplifier is an electronic device that is capable of intensifying the electrical energy produced from a sensor, on in a transmission path it is capable of enhancing the signal. As the distance that the signal is transmitted increases, the more the signal weakens and distorts. Consequently, on long runs of the communication facility, an amplifier must be put in line to restore the signal strength.

3.5.2 Repeaters

This is an electronic device that amplifies and restores the signal characteristics, such as frequency and signal form. These are a special class of device that assure the integrity of the signal at any distance from the transmitting source. The savings of longer runs of cable, or other media, must be traded off with the required repeaters.

3.5.3 Computer Interface Unit

There is a need for encoding and decoding identifying information and traffic data at the detector location, and control protocol at the master controller or traffic control center. A computer interface unit, possibly a microcomputer with appropriate software, takes the identifying information and traffic data, or control protocol, and puts it in the appropriate form. At the receiving end, the traffic data stream must be decoded to yield the traffic data or information in the necessary form.

3.5.4 Modulators/Demodulators

The binary stream of data and/or information must be configured in a form that is compatible with the transmission path, unless it is directly coupled. The modulation and demodulation of the original data and information in AM, FM, or PSK, as previously discussed, is accomplished with this equipment known as a modem.

As indicated, if there is a direct coupling of the controller and the detectors, or the controller and the signals, a modem is not required.

The modem serves as the interface between the traffic detectors and the communications media, and the communication media and the controller. The modem function largely eliminates the concern by the traffic engineer of the actual communication channels characteristics and the nature of the modulation and demodulation. The only relevant concerns about the communication channel and the nature of the signal modulation are the transmission rate and the reliability of the data.

3.6 LIMITATIONS AND CONSTRAINTS

There are a wide variety of limiting factors and variables that influence the selection of a communications media. These limitations and constraints may preclude the use of a particular communications media for a given setting.

3.6.1 Nature of the Data

The full range of communication media can be used where only traffic count data are to be sent. However, if vocal or video transmission must be accommodated, the media that can be used are more restrictive. For example, presently it would be difficult to transmit video over leased phone lines. The communication channel can support it, but the necessary peripheral equipment is not readily available.

3.6.2 Data Rate and Number of Functions

The rate at which data must be transmitted and the number of functions for which control protocol must be sent. Twisted wire pairs can transmit up to1200 bps, however, if the data transmission rate must be greater, additional electronic equipment must be provided. (1)

The new technology development for copper twisted wire pairs to increase data rates include the High-bit-rate Digital Subscriber Line (HDSL) technology and Asymetric Digital Subscriber Line (ADSL) are examples; HDSL is providing up to 2 Mbps for short distance, about 1 mile in length, and up to .6 Mbps using ADSL. (14)

The typical data transmission rate capabilities of the various media are given in Table 3.1.

Table 3.1 Typical Data Rate

Media	Data Rate (kilobits/sec)
Twisted Wire Pairs	0.3 – 56
Coaxial Cable	300 – 10,000
Fiber Optic Cable	1 – 1,000,000
Radio	1.2 – 9.6
Microwave	9.6 – 155,000
Infrared	0.05 - 20

Source: *IEEE Spectrum*, June 1994

3.6.3 Reliability

The reliability of the transmission data and information must look at all components of the communications subsystem. The complete failure or random failure of any component may cause the entire communications subsystem to fail because the subsystem is largely linear, and with dependence of the control system on communication, the entire system would fail. Reliability can be provided by adding redundancy to critical components of the system. This may require two or more parallel communication channels as a backup capability. Critical equipment at important locations in the transportation network should also have a capability to operate independently for a short time. One of the major strengths of leased telephone lines is the redundancy and thus, reliability provided by their systems.

The more highly connected and hierarchical the traffic control system is to a central controller or traffic control center, the greater the potential for failure at some location in the system. This problem can be avoided by distributing the control and decision making to various locations throughout the system.

3.6.4 FCC Rules

There are limitations and rules imposed by the Federal Communications Commission. Wire pairs must conform to the Interstate Tariff FCC No. 260 for a private line in the voice band when leased from a telephone company. If leased from a cable TV company, interference radiation requirements in the FCC Rules for Cable Television must be met.

3.6.5 Normal Operating Range

The normal operating range for the various communications media may also serve as a limitation on their use. A comparison of the ranges of these media are given in Table 3.2.

Table 3.2 Normal Operating Range, meters

Media	Range
Twisted Pairs	1 – 1000
Coaxial Cable	10 – 10,000
Fiber Optic Cable	10 – 60,000
Radio	50 – 10,000
Microwave	1,000 – 10,000
Infrared	0.5 – 30

Source: *IEEE Spectrum*, June 1994

3.7 COSTS

The mix of costs of each of the communications is somewhat different. The primary costs are initial capital costs, operating costs, maintenance and repair costs, and lease fees. Many of these costs are specific to the geographic ara, and even to the site, where the service is located.

A study performed for Plano, Texas to evaluate the communication technology that they should use for their future traffic signal expansion gave the comparative results shown in Table 3.3. This application was to receive data from both traffic detector and

CCTV and control information is to return to only traffic signals. Control of CCTV units is to provide dial-up phone service.

Table 3.3 Ranking of Communications Media Costs in Plano, Texas

	Capital Costs	Operating Costs
Coaxial Cables	1.0	4.5
Fiber Optic/Coaxial Cable*	2.0	4.5
Leased Line**	5.0	1.0
Spread Spectrum	3.0	3.0
Spread Spectrum/ Leased Line***	4.0	2.0

* Existing fiber optics stands would be connected to coaxial cable at the center and at the site

** Leases dedicated telephone line

*** Combination of some spread spectrum and some leased

Ranking order: 5 (best) and (1) worst

A complete analysis of the costs for this study using the net present value method found the results shown in Figure 3.3. In this setting, a combination of spread spectrum and leased telephone lines proved to be the most economic over time.

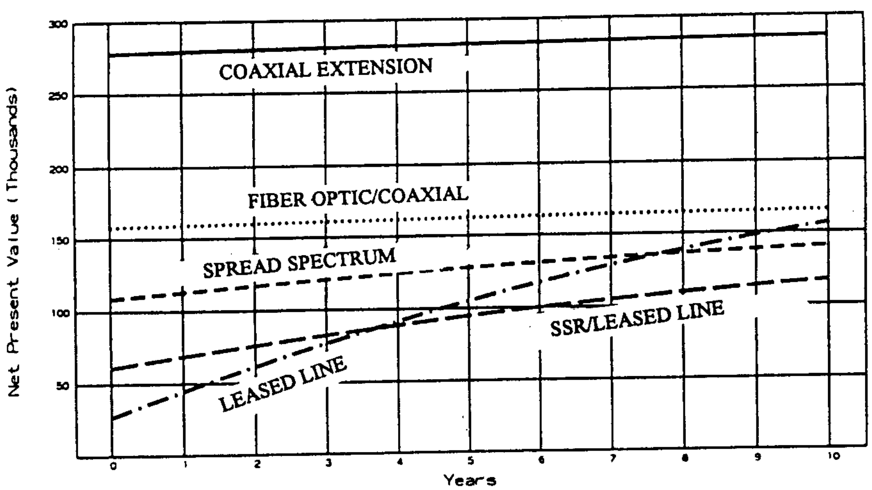

Figure 3.3 Comparative Net Present Value of Various Communications Media on Plano, TX Travel Surveillance Installation

The economy of leased lines was demonstrated by this study, in this situation.

A qualitative rating of the installation costs for various communications were presented in the IEEE Spectrum for June 1994, as shown in Table 3.4. As would be expected, the physical hard wire media have higher installation costs than the air path media.

Table 3.4 Comparative Rating Installation Costs

Media	Installation Cost
Twisted Pairs	High
Coaxial Cable	High
Fiber Optic Cable	High
Radio	Low – Medium
Microwave	Medium
Infrared	Low

Source: *IEEE Spectrum*, June 1994

If the laser technology were included in the above table, it would be expected to be medium, because the supports for the transmission and reception diodes must be constructed to remain virtually motionless.

The impact of installing the media underground as compared to overhead can be seen from the Traffic Signal System Master Plan for Multnomah County, Oregon. This study by Kittelson and Associates estimated that the costs of twisted wire pairs installed in a conduit underground would be 8.3 times more than installed overhead.

Virtually all of the communications media require a modem to modulate and demodulate the signal at the detector end and at the controller end, respectively. The relative modem costs are given in Table 3.5.

Table 3.5 Relative Modem Costs

Media	Relative Modem Costs
Twisted Pairs	$300
Coaxial Cable	$30 - $50
Fiber Optic Cable	$300 - $1000
Radio	$600 - $3000
Microwave	$10,000 - $90,000
Infrared	$20 - $75

Source: *IEEE Spectrum*, June 1994

3.8 CONSTRUCTION AND LOCATION CONSIDERATIONS

Construction and location consideration are primarily related to the hardwire type of media. The communication media typically is located in the roadway right-of-way and may include underground conduits, direct burial cable, or overhead cable. Cables placed in buried conduits yield the least maintenance because damage from weather, accidents or maintenance activities is less. The costs of the conduit, according to the DKS study for Portland, are given in Table 3.6.

Table 3.6 Unit Costs for Conduit Installation

Type	Unit Cost
Trenching in ditch	$6.00/ft
Trenching in asphalt	$8.00/ft
Trenching in concrete	$16.00/ft
Bore/jack across freeway	$50.00/ft*
Pull boxes	$250/ea
PVC conduit (2-3")	$2.50/ft
Metal conduit (2-3")	$5.00/ft
* A $500 move in/setup fee for each location ** Assumes 400 ft spacing of pull boxes at interchanges	

Source: *Portland Freeway Management Systems Network Communications Technical Memorandum, No. 2,* DKS & Assoc., Portland, OR 1991

A proposed design alternative for the Portland system would place the conduit in the embankment or cut slope with a shoulder of adequate width to allow maintenance without closing any travel lanes. (9)

A key part of the construction activity is the assurance that the design and particular component specifications are strictly followed. For fiber optic cables, the alignment tolerances must be met. For buried cable or conduit, there must be adequate quality control and care to assure that the cable will not be broken, crushed or frayed in construction, subjecting it to electrical short circuits, noise, or interference from water impregnation. The specifications for the cable should include the insulation requirements, the color coding, physical size, and electrical properties.

The location of the communications media facilities must be accomplished jointly with the development of the traffic control system. The type of traffic control system, that is, central control, distributed control, etc., determine the need and corridors where communications media must be provided.

3.9 OPERATIONS AND MAINTENANCE

The operations of the traffic control system depends on the communications link, but the communications subsystem operates virtually automatically unless there is a problem. The ease of maintenance is important. A preventive maintenance program assures effective and reliable traffic control. The more sophisticated recent technology, such as, fiber optics, spread spectrum radio, or laser, may require a level of experience and expertise for maintenance that exceeds the jurisdictions' ability. Consequently, the jurisdiction may elect to use simpler, more easily maintained media or contract-out maintenance to a qualified contractor. Service could also be leased from the local telephone company or cable TV company.

Maintenance problems often are caused by weather conditions and construction errors. Lightening is a major contributing cause to the failure of communication equipment and cables. Construction activities or errors that cause potential maintenance problems include:

- Improperly installed cable or connections
- Cable pulling tension exceeds maximum allowable
- Inadequate coverage of earth
- Sharper turning radii in bends than allowed

- Improper splicing

Activities that can potentially cause maintenance problems include:

- Damage from excavation
- Installation of utility poles or signs

Overhead cable installations are the least costly for installations, however, there is often a rental/lease fee for the use of the utility poles. Cables in overhead installations experience slow deterioration due to exposure to ultraviolet light, resulting in a cable life of 15 years. This is a life significantly less than for buried cables at 20-25 years. (3)

4.0 NATIONWIDE SURVEY

A nationwide survey was conducted to collect information about which technologies are employed in other states. The following questions were asked:

- What technology do you use for freeway detection/information collection?
- How and where do you transmit the data/information collected for each type of technology listed?
- Why did you select the media that you used to transmit data/information?
- What was the initial cost of installation and maintenance?
- Have you updated or improved your surveillance system, and particularly your data transmission/communications media?
- What are you current costs for improvement and maintenance?
- Have you had any specific problems with the media?
- Are there specific advantages that you have observed for each transmission/communication medium?
- Are there specific disadvantages that you have observed for each transmission/communication medium?

Responses were provided by:

1. Kansas Department of Transportation
   Terry W. Heidner
   Chief of Transportation Planning

2. City of Columbus
   Division of Traffic Engineering

3. California Department of Transportation – CALTRANS
   Patricia P. Perovich
   Chief, Traffic Systems Branch

4. City of Los Angeles
   Department of Transportation
   Anson Nordby
   ATSAC Division Engineer

5. Minnesota Department of Transportation
   Traffic Management Section
   Glen Carlson
   Utah Department of Transportation
   Division of Traffic and Safety

6. JHK & Associates, Transportation Systems

7. Texas Department of Transportation
   Patrick F. McGowan

Traffic Management Engineer

Nine questionnaires were completed and received which describe various jurisdictions experience with various communications media. The following is a discussion of the important findings. Summaries of the responses and direct quotes in response to the questionnaire are reported.

4.1 QUESTION 1 – "What technology do you use for freeway detection/ information collection?"

The response indicated that all nine of the agencies use loop detectors to collect traffic data on the mainline of the freeway and ramps. Some use that data to perform ramp metering. Eight of the nine agencies also collect data by way of CCTV. Some agencies rely on additional data collection methods, including aerial surveillance, CB radio/phones for incident detection and freeway service patrols.

4.2 QUESTION 2 – "How and where do you transmit the data/information collected for each type of technology listed above?"

The results from this question show that the traditional hardware communications are still receiving substantial use. For the study group, the following use distribution for communications media:

Twisted wire pair from detection to the Traffic Management Center	-- 3
Twisted wire pair lead in to controller	-- 3
Coaxial cable to TMC	-- 4
Fiber optic cable to TMC	-- 4
Leased phone lines	-- 4
Microwave transmission (for CCTV)	-- 1
Cellular phone	-- 1
SMR, voice/data radio system	-- 1

One agency response indicated their plan to use fiber optic cable for their next project. Also, lease phone lines are being replaced by state owned lines.

4.3 QUESTION 3 – "Why did you select media that you used to transmit data/information?"

There are similarities in the answers. However, this decision is very important so a summary of responses was not felt to be appropriate.

- Consultant design recommendation, based on capacity and economics
- Most cost effective
- Consistent with past practice
- Coaxial most practical in the 1970s and early 80s. In late 80s technical advantages made fiber optics more attractive
- Reliability of leased phone lines
- Coaxial cable is media used for all of UTCS signal system
- Twisted wire pairs are inexpensive ... (and) easily expanded
- Fiber optic cable provides technological advantages
- Met the required bandwidth
- (State of the art) technology at time of design
- Established investment in existing field infrastructure
- Service available for lease at time of implementation

The primary reasons appear to be that the selected alternative is:

- Most cost effective
- Consistent with past practice and existing system
- Reliable
- State-of-the-art, when implemented or at the present
- Met technological requirements.

4.4 QUESTION 4 – "What was the initial cost of installation and maintenance?"

This question was difficult to evaluate since other costs were often included. Also, some projects were evaluated over their expected life.

- Fiber optic cable installed at $100,000 per mile with no maintenance to date
- Coaxial cable installed at $295,000 (Canadian) per mile and $459,000/mile, as compared to $2,250,000/mile for fiber optic cable with civil work included
- Average installation per site is $80 (for telephone service), and average monthly maintenance is $30.00

4.5 QUESTION 5 – "Have you updated or improved your surveillance system, and particularly your data transmission/communications media?

Technology for communications is improving and evolving. This question ascertained how many agencies are attempting to take advantage of these improvements in technology.

- Eight of nine agencies indicated that they are updating their communications technology
  - -- 4 agencies plan on using fiber optics cable
  - -- 2 agencies the study is underway but no decision has been reached
  - -- 1 agency is using coaxial cable
  - -- 1 agency is installing new phone lines and connections
- The other agency is just installing their first system

4.6 QUESTION 6 – "What are your <u>current</u> costs for improvement and maintenance?"

Most agencies contacted had current costs for improvement and maintenance that was equal to the projects they have underway. Otherwise, this information was not available.

- Approximately $180 million for design and construction of a total traffic surveillance and control system (Los Angeles)
- HAR costs are about $2.5 million/year (Los Angeles)
- Leased phone lines, $2 million/year
- $13,000 per installed loop

4.7 QUESTION 7 – "Have you had any specific problems with the media?"

The problems with communications media are numerous and diverse. The questionnaires yield a sample of some of the wide variety of problems experienced with various communications. Most problems have been identified and are expected.

- Necessary improvements to avoid obsolescence will be unreasonably costly if undertaken prematurely, before the adopted technology was perfected
- Noise on telephone lines

- Aerial coaxial cable experienced breakage due to rapid temperature changes with consequent cable expansion and shrinkage
- Lightening damage to electronics and water in underground connections
- Older coaxial cable installations have limited channel capacity and RF interference problems
- Initial installation of leased lines and connections can be complicated and time consuming
- Coordinating repair efforts with the phone company can be troublesome at times
- Minor interference problems with twisted wire pairs
- Some modem failures
- Contractor installation problem, specifically, poor splices and solder joints
- Some microwave transmission problems because of line-of-sight to the location of traffic operations center in downtown Los Angeles
- Unreliable leased line service, slow maintenance response from lease carriers, unpredictable lease line costs
- Construction disruption of twisted cable pairs

One new problem identified by the questionnaires is the criticality of determining the appropriate media to update obsolete technology, and the importance of the timing of that decision for cost effectiveness.

4.8 QUESTION 8 – "Are there specific advantages that you observed for each transmission/communication medium?"

As with the problems in Question 7, it was anticipated that most of the advantages for a communication media were known.

- Grid redundancy of leased telephone lines
- During catastrophic events, telephone personnel would be available to repair problems for leased lines
- Leased satellites correct right-of-way and line-of-sight frequency interference problems
- State owned twisted wire pairs provide control over the repair process when necessary
- Fiber optic equipment gives clean, clear signals

- Ability to transmit video as well as traffic data over coaxial cables
- Fiber optic system does not require periodic tuning
- Coaxial cable is a mature technology; it is easy to train maintenance personnel (for its repair)
- With leased telephone lines, the agency does not have to trouble shoot problems in the telephone line
- Fiber optics allow more bandwidth for data transmission, reduce costs for leasing phone lines, improve efficiency of space, allow more flexibility for expansion and reduce maintenance costs.

No new advantages were identified; however, some additional positive impacts were seen. For example, telephone repair performed by telephone personnel in catastrophes frees agency personnel to deal with other problems.

4.9 QUESTION 9 – "Are there specific disadvantages that you have observed for each transmission/communication medium?"

As with the advantages, many of the disadvantages spelled out in the questionnaire responses have already been identified in other sources.

- Fiber optics are costly
- Problems with microwave frequency licensing
- Line of sight requirements for microwave
- The price of telephone service
- Telephone personnel are not able to identify noise problems
- Coaxial cable requires tuning twice a year and requires more amplifiers per unit of distance
- Fiber optic connectors require careful handling
- Twisted wire pairs typically do not have backup in case of failure
- Twisted wire pairs are susceptible to electromagnetic interference
- Twisted wire pairs are unable to support video transmission
- Fiber optic cables have higher terminal equipment costs (than other media)

4.10 QUESTION 10 – "Other comments"

Two questionnaires had additional relevant and valuable comments.

- Most of the other forms of data transmission (other than telephone) are either too complex or are not feasible for reliable communications. The telephone system may be expensive; however, the connection is highly reliable.
- Coaxial cable
  1. Limited capacity; good for small network
  2. Mature technology; easy to find equipment
  3. Ingress problem
- Fiber optics cable
  1. The cable itself is maintenance free
  2. It is difficult to splice and terminate the cable

4.11 SUMMARY OF QUESTIONNAIRES

The responses to questionnaires are varied and relate to various communications media. However, there are some general conclusions that can be drawn from the questionnaire.

- The technology for communications is evolving and improving, and the highway engineering community is embracing the changes and implementing the new technology as it becomes available.
- The use of leased telephone service has fairly widespread acceptance and use. The reliability of this technology is an important trait.
- Fiber optics cable is the new technology receiving the greatest attention.

5.0 TYPICAL APPLICATIONS AND FUTURE TECHNOLOGY

The communication of traffic data and related information is complex and requires an understanding of the electronic technology. The findings from this study have shown that the communications technology are not generally applicable. Certain media lend themselves better to specific locations and conditions, due to the respective strengths and advantages.

Two applications are presented in this section to explore the typical communications that might be found in these situations.

5.1 APPLICATIONS IN SMALL CITIES OF ABOUT 200,000 POPULATION

A major consideration in the determination of the traffic control system design is the length of the communications links. The layout and organization of the traffic control system must be taken into account in the selection and design of the communications subsystem.

The type of data to be transmitted limits the options. If closed circuit television (CCTV) is to be used, and the video signal transmitted over the same media as the traffic data, some media cannot be used. The *Communications Handbook for Traffic Control Systems* defines a comprehensive procedure for selecting the communications architecture and technology. This procedure is shown in Figure 5.1 from that reference.

The media technology that is most applicable to small cities are primarily the hardware, leased phone and cable TV service or local area radio networks. In general, it requires a large signal network before microwave technology is economic.

Many smaller cities have relied on twisted line pairs, coaxial cable and recently fiber optic cable. These media all have the ability to transmit both traffic data and the video signal. One consideration is the distance limit on the various hardware cables before a repeater must be installed to restore the signal.

The city of Stockton, about 300,000 population in the metropolitan area, in upgrading their traffic signal system has selected the fiber optic alternative (21). Many other cities of this approximate size are electing to use media that are not relying on the normally accepted technology for smaller cities.

The evaluation of the signal system improvements in Plano, TX, looked at coaxial cable, fiber optics/coaxial cable, spread spectrum, spread spectrum/leased line, and leased line (13). Their economic evaluation ranked lease line best with spread spectrum/leased line second. Considering a number of factors, including reliability,

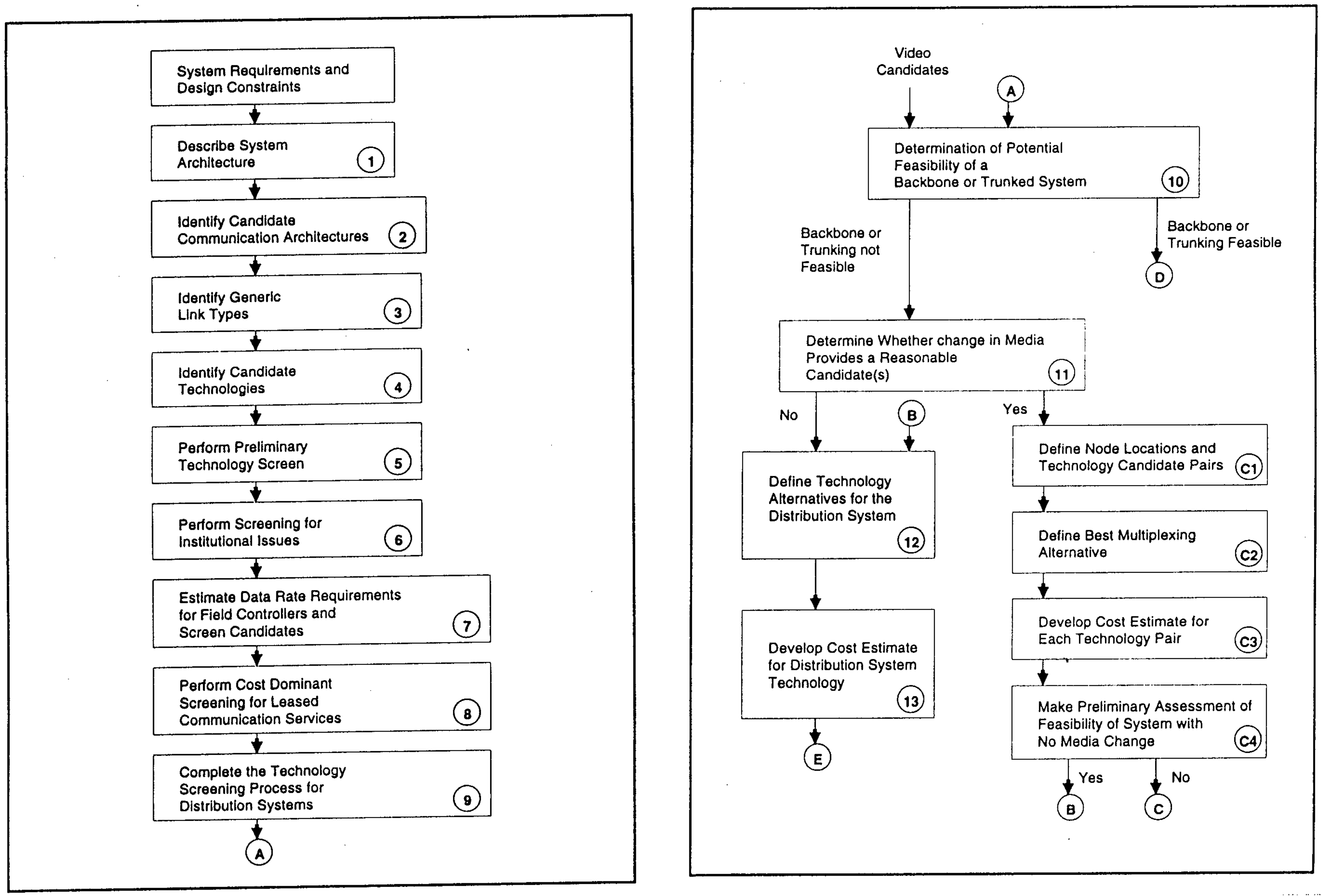

Figure 5.1 Procedure for Selecting Communications Architecture and Technology (Source: Reference 3)

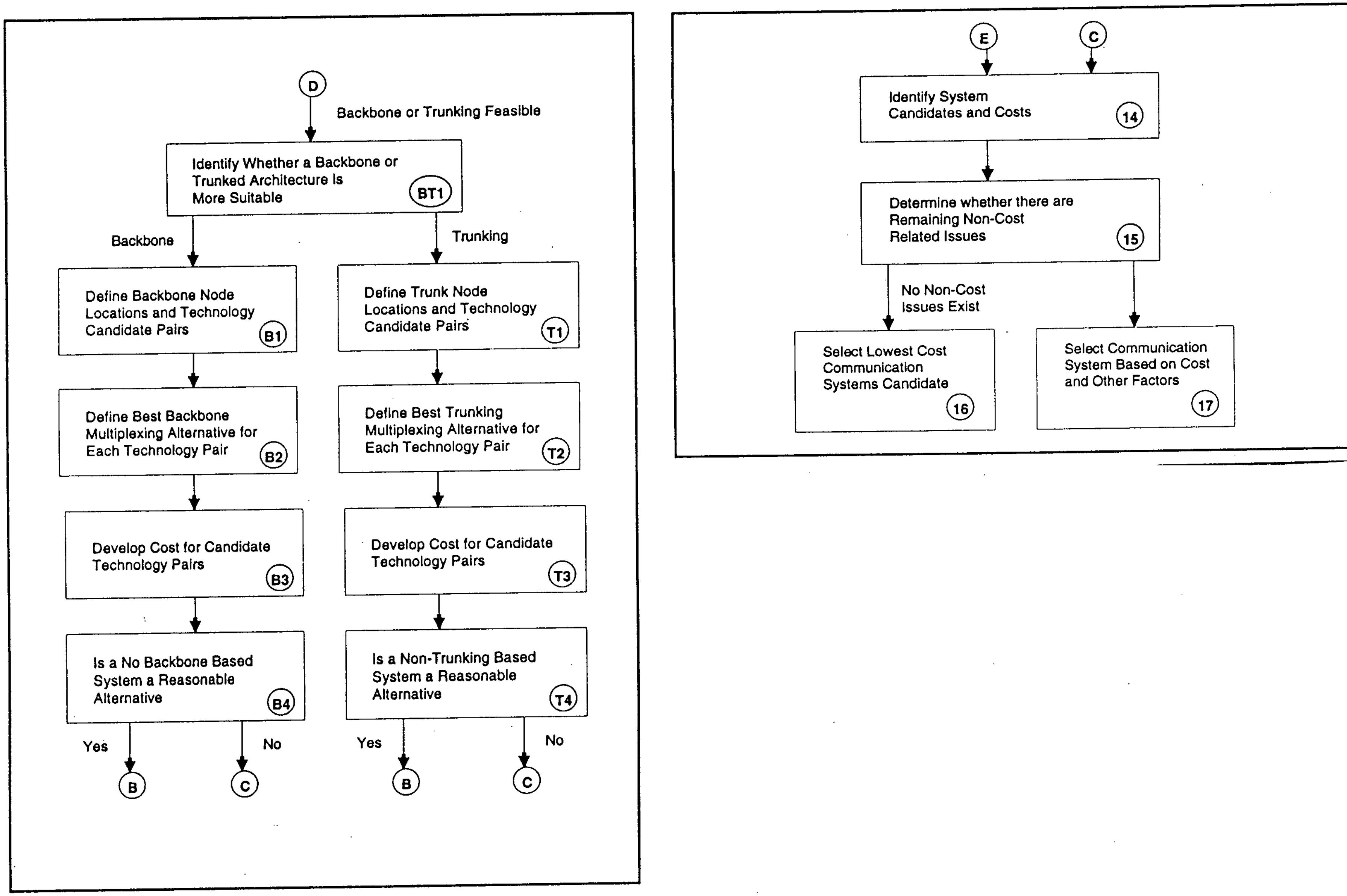

Figure 5.1 Procedure for Selecting Communications Architecture and Technology (cont) (Source: Reference 3)

capital cost, operating cost, flexibility, quality, engineering costs and time to implement, the leased line alternative received the highest rating.

The city of Petaluma selected the spread spectrum radio technology for their communications media (22). The city of Farmington, NM, has elected to use radio communications over cable TV leased lines or dial-up and leased telephone lines (25).

5.2 APPLICATIONS IN LARGE URBAN AREAS

The typical situation for larger urban areas is the presence of an existing, often near obsolete, system and the use of a variety of communications technology. The size of system and the length of the communications links open the application to the full range of media available. Often, the older technology, twisted wire pairs and coaxial cable (user owned), cannot compete economically.

The city of Portland street system presently uses copper twisted wire pairs and leased cable TV lines for their communications media. The new freeway traffic surveillance and control system intends to use fiber optics cable with microwave and user lease of telephone lines to remote sites (26).

The San Francisco Bay Area, CALTRANS District 4, also uses a number of communications media, including coaxial cable, video over leased lines, leased telephone lines, local area radio network and cellular phone (18). The communications component is expected to be the most costly part of the development of the Traffic Operations System. The future development of the Traffic Operations System considered

- dedicated lines
- leased lines
- leased satellite
- microwave
- radio
- infrared
- cellular radio

The alternative selected for future development is leased lines.

5.3 FUTURE COMMUNICATIONS TECHNOLOGY

There are other communications that are available and in evolution. These include:

- SONET Technology – This refers to synchronous optical network. The viability of this service has been made possible by significant improvement in optical transceivers (14). This service is already seeing significant use today, but has major potential for use in the future.
- A.T.M. Technology – This technology will compete with the ETHERNET (14).
- Leased Network Service – An increased growth in competing network services available for lease/call-up service (14).
- MPEG-II, Version X Compression – The MPEG-II video compression/ decompression algorithm is expected to become a national standard. Chips will be available so CCTV cameras will output compressed video that is in standard form, eliminating the separate video switch and communications switch (14).
- Cellular – CDMA will be selected as the standardized digital cellular wireless communications system, with enhanced capability (14).
- Digital Microwave – The FCC will change regulations on bandwidth to allow their increase. Power limit will be modified (14).
- Satellite – Wireless – Wider bandwidth satellite channels will be available at lower cost (14).

It is expected that future communications technology will replace twisted wire pairs and coaxial cables in the next 10 to 20 years.

6.0 CONCLUSIONS

There are some obvious conclusions to be drawn regarding communications media for traffic control:

- Old technology of twisted wire pairs and coaxial cable still has its place and is not obsolete.
- Recent technological developments for coaxial cable has increased its capacity and flexibility.
- Fiber optics cable is the hard wire cable choice for the future.
- Leased lines remain a sound, economic alternative when all factors are considered.
- Many air-path link alternatives are becoming more attractive as evolutions in the technologies continue.
- Careful study of each project application should be undertaken since site-specific factors can affect the decision.

6.1 RECOMMENDATIONS

There are some clear recommendations arising from this study. There are numerous and diverse communications media. Many factors and variables influence the implementation, operation and maintenance of the communications channels.

- A comprehensive study should be made of the entire traffic operations system to assure that the communications subsystem is well integrated with the control and information subsystems.
- Where twisted wire pair and coaxial cables have been selected, construct the system with conduit to permit ready upgrade to fiber optic cable.
- Where telephone or CATV leased lines are being employed, get firm, enforceable agreements on the timing and quality of maintenance.

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Appendix

Questionnaire Responses

Agency:

JHK & Associates, Transportation Systems
Engineering Consultants to California Department of Transportation
District 4, San Francisco Bay Area
Michael Butler for Craig Gardner

Freeway Surveillance Site:

The San Francisco Bay Bridge
I-880 Alameda, Santa Clara Counties

I. What technology do you use for freeway detection/information collection? (Please indicate all, such as CCTV, ramp metering with loop detectors.)

1. CCTV
2. Loop IR Detector
3. Freeway Service Patrol
4. 911 Call-in System, California Highway Patrol

II. How and where do you transmit the data/information collected for each type of technology listed above? (for example: 1. coaxial cable to central control center, 2. twisted wire pairs to controller at metering location.)

1. Coaxial Cable to Bridge Toll Office, Conferenced Digital Video Over Leased Lines to TMC.
2. Leased Telephone Lines
3. SMR, Voice/Data Radio System
4. Cellular Telephone

III. Why did you select the media that you used to transmit data/information?

Most reasonable interim media, pending construction of a TOS infrastructure

IV. What was the initial cost of installation and maintenance:

Not Available

V. *Have you updated or improved your surveillance system, and particularly your data transmission/communications media?*

A new TOS design underway

VI. *What are your current costs for improvement and maintenance?*

Not Available

VII. *Have you had any specific problems with the media?*

Enclosed find a draft version of the Bay Area Traffic Operations System Concept Design Communications chapter

VIII. *Are there specific advantages that you have observed for each transmission/communication medium?*

Enclosed find a draft version of the Bay Area Traffic Operations System Concept Design Communications chapter

IX. *Are there specific disadvantages that you have observed for each transmission/communication medium?*

Enclosed find a draft version of the Bay Area Traffic Operations System Concept Design Communicatons chapter

X. *Other comments:*

THANK YOU AGAIN FOR YOUR ASSISTANCE AND EFFORT.

(8-20-92)

COMMUNICATIONS MEDIA FOR FREEWAY
SURVEILLANCE AND CONTROL

Agency: Kansas Department of Transportation Planning
Traffic & Field Operations Unit

Freeway Surveillance Sites: All Automatic Traffic Recorder Sites throughout the state.

I. What technology do you use for freeway detection/information collection?

1. We utlize loop detectors for all freeways.

II. How and where do you transmit the data/information collected for each type of technology listed above?

1. The data is transferred via telephone to either the technician's shop or central office.

III. Why did you select the media that you used to transmit data/information?

The telephone was chosen over other types of communication due to reliability.

IV. What was the initial cost of installation and maintenance?

The average installation per site is $80.00, and the average monthly maintenance is $30.00. Currently we have twenty five sites on line for an installation price of $2,000. Since we had no telephone lines initially, the maintenance was $0.00.

V. Have you updated or improved your surveillance system, and particularly your data transmission/communications media?

We have upgraded our surveillance system and are currently utlizing Diamond TT-2001 systems. We are also slowly installing telephone lines at our ATR sites. We have encountered some problems with our Modem's but hopefully we will resolve them soon.

VI. What are your <u>current</u> costs for improvement and maintenance?

We currently are spending $700.00 per month on maintenance and will be increasing this amount until all ninety nine sites are on telephone lines.

VII. Have you had any specific problems with the media?

We have had two problems with noise on the telephone line however both of the problems have been fixed. We also did not know all of the technical terms to place on our telephone orders, however through several installtions we have come to know these terms.

VIII. Are there specific <u>advantages</u> that you have observed for each transmission/communication medium?

The one major advantage is the fact that we do not have to trouble shoot the telephone lines when there is a problem which allows us to concentrate on any surveillance unit problems.

IX. Are there specific <u>disadvantages</u> that you have observed for each transmission/communications medium?

The price is the first disadvantage. The second disadvantage is the fact that some of the telephone repair people are not able to diagnose a noise problem on the telephone line. When the telephone person called our surveillance site, they said they heard the modem answer, however there was too much noise on the line to download the site.

X. Other Comments:

Most of the other forms of data transmission are either too complex or are not feasible for reliable communications. The telephone system may be expensive, however the connection is highly reliable.

COMMUNICATIONS MEDIA FOR FREEWAY SURVEILLANCE AND CONTROL

Agency:

Ministry of Transportation of Ontario

Freeway Surveillance Site:

Refer to Attachments 1, 2, and 3

I. What technology do you use for freeway detection/information collection? (Please indicate all, such as CCTV, ramp metering with loop detectors.)

1. CCTV
2. VDS (Vehicle Detection Subsystem) with loop detectors
3. Ramp metering with loop detectors

II. How and where do you transmit the data/information collected for each type of technology listed above? (for example: 1. coaxial cable to central control center, 2. twisted wire pairs to controller at metering location.)

Two types of media were implemented:

1. coaxial cable to central control centre
2. fibre optic cable to central control centre

III. Why did you select the media that you used to transmit data/information?

1. In 1970's and early 80's, coax iS the only feasible solution for our application.
2. Late 80's, fibre became a more attractive option due to the technical advantages: large bandwidth, high speed, immune to EMI interface, etc..

IV. What was the initial cost of installation and maintenance:

Refer to Attachments 1, 2, and 3

(cont'd-over)

V. *Have you updated or improved your surveillance system, and particularly your data transmission/communications media?*

Since 1975, some of the coaxial cable has been replaced.

VI. *What are your current costs for improvement and maintenance?*

There is no specific improvement to the media other than total replacement of the cable.

See Attachments for supplementary information.

VII. *Have you had any specific problems with the media?*

For aerial coaxial cable, there was a breakage problem due to rapid temperature change causing cable expansion and shrinking.

VIII. *Are there specific advantages that you have observed for each transmission/communication medium?*

- Fibre system does not require periodic tuning
- Coax system is a mature technology, it is easy to train our maintenance personnel

IX. *Are there specific disadvantages that you have observed for each transmission/communication medium?*

- Coax system requires tuning twice every year; requires more amplifiers to cover a particular distance
- The fibre connectors that we use (ST) require careful handling

X. *Other comments:*

- Coax:
  1. limited capacity; good for small network
  2. mature technology; easy to find equipment
  3. ingress problem
- Fibre:
  1. the cable itself is maintenance free
  2. it is difficult to splice and terminate the cable

THANK YOU AGAIN FOR YOUR ASSISTANCE AND EFFORT.

COMMUNICATIONS MEDIA FOR
FREEWAY SURVEILLANCE AND CONTROL

Agency: CITY OF COLUMBUS
DIVISION OF TRAFFIC ENGINEERING

Freeway Surveillance Site: COLUMBUS FREEWAY SYSTEM

I. What technology do you use for freeway detection/information collection? (Please indicate all, such as CCTV, ramp metering with loop detectors.)

1. CCTV
2. LOOPS
3.

II. How and where do you transmit the data/information collected for each type of technology listed above? (for example: 1. coaxial cable to central control center, 2. twisted wire pairs to controller at metering location.)

1, COAXIAL, CAMERA SITE TO CENTRAL
2. LOOP LEAD-IN TO CONTROLLER CABINET

III. Why did you select the media that you used to transmit data/information?

COAXIAL CABLE IS THE MEDIA USED FOR OUR UTCS SIGNAL SYSTEM

IV. What was the initial cost of installation and maintenance:

APPROX $2.00 LF

(cont'd-over)

V. Have you updated or improved your surveillance system, and particularly your data transmission/communications media?

IN THE PROCESS OF HIRING A CONSULTANT TO ASSIST WITH DESIGN OF A FULL FREEWAY TRAFFIC MANAGEMENT SYSTEM

VI. What are your current costs for improvement and maintenance?

NOT SPECIFICALLY BROKEN DOWN

VII. Have you had any specific problems with the media?

LIGHTNING DAMAGE TO ELECTRONICS, WATER IN UNDERGROUND CONNECTIONS - NOTHING THAT IS NOT COMMON TO CCTV INDUSTRY

VIII. Are there specific advantages that you have observed for each transmission/communication medium?

ABILITY TO TRANSMIT VIDEO - WE USE A PORTABLE CAMERA FOR STUDIES

IX. Are there specific disadvantages that you have observed for each transmission/communication medium?

NO

X. Other comments:

WE WILL BE LOOKING STRONGLY AT FIBER OPTIC FOR THE NEXT PROJECT

THANK YOU AGAIN FOR YOUR ASSISTANCE AND EFFORT.

(8-20-92)

COMMUNICATIONS MEDIA FOR
FREEWAY SURVEILLANCE AND CONTROL

Agency: Mn/DOT - Traffic Management Center
1101 - 4th Ave. South
Minneapolis, MN 55404

Freeway Surveillance Site: Twin Cities Metro Area

I. What technology do you use for freeway detection/information collection? (Please indicate all, such as CCTV, ramp metering with loop detectors.)

1. Ramp metering with loop detectors & Type 170 Controllers
2. CCTV
3. Aerial surveillance via partnership with commercial radio stations

II. How and where do you transmit the data/information collected for each type of technology listed above? (for example: 1. coaxial cable to central control center, 2. twisted wire pairs to controller at metering location.)

Fiberoptic cable for CCTV to Traffic Mgmt Center (TMC), & for data transmission (2 way) between TMC & mux cabinets.
Twisted pair for data transmission (2 way) between mux cabinets & 170 Controllers

III. Why did you select the media that you used to transmit data/information?

Consultant design recommendation based on capacity & economics.

IV. What was the initial cost of installation and maintenance:

Fiberoptic cable installed @ $100,000/mile.
No maintenance experience to date

(cont'd-over)

V. Have you updated or improved your surveillance system, and particularly your data transmission/communications media?

No updating yet – when it occurs, fiberoptic cable will be the media.

VI. What are your current costs for improvement and maintenance?

Refer to IV. – Installation, or "improvement", is $100,000/mile. Fiberoptic is our new design standard so we do not have maintenance experience with it.

VII. Have you had any specific problems with the media?

Older installations of coaxial cable have limited channel capacity and RF interference problems.

VIII. Are there specific advantages that you have observed for each transmission/communication medium?

Fiber optic equipment gives clean, clear signals.

IX. Are there specific disadvantages that you have observed for each transmission/communication medium?

Refer to VII

X. Other comments:

Please send me a copy of your report.

Thanks!

Glen Carlson

612-341-7500

THANK YOU AGAIN FOR YOUR ASSISTANCE AND EFFORT.

(8-20-92)

COMMUNICATIONS MEDIA FOR FREEWAY SURVEILLANCE AND CONTROL

Agency: Illinois Dept of Transportation
Traffic Systems Center

Freeway Surveillance Site:
Chicagoland Area freeway network
(District One)

I. What technology do you use for freeway detection/information collection? (Please indicate all, such as CCTV, ramp metering with loop detectors.)

1. • All mainline sensors are either 6'x6'
2. square or 6' diameter circular induction loop detectors.
3. • CB radio installations remotely monitored over dial-up telephone lines for incident detection/verification.

• Future contract will provide CCTV for JFK section of I 90/94.

II. How and where do you transmit the data/information collected for each type of technology listed above? (for example: 1. coaxial cable to central control center, 2. twisted wire pairs to controller at metering location.)

1. Leased phone lines to/from field location & control center (60% - 70%).
2. State-owned copper facility (twisted pair) in median barrier wall duct to/from field locations & control center (30% - 40%)
3. Future contract will provide first fibre optic link '94.

III. Why did you select the media that you used to transmit data/information?

1. Most cost effective means (Chicago project originated in 1961) during this time.
2. System expansions continued this practice, but leased lines now being replaced with state-owned cable during freeway rehabilitation projects.

IV. What was the initial cost of installation and maintenance:

(needs to be more specific)

(cont'd-over)

V. *Have you updated or improved your surveillance system, and particularly your data transmission/communications media?*

(See parts II & III above)

VI. *What are your current costs for improvement and maintenance?*

- Construction costs on new surveillance jobs when averaged over the number of loops to be installed are running ~ $13K (includes equipment)
- The surveillance portion of the Districts electrical maintenance contract is ~ $4 mil. per year.

VII. *Have you had any specific problems with the media?*

Initial installation of leased lines can be complicated & time consuming. Coordinating repair efforts with the phone company can be troublesome at times.

VIII. *Are there specific advantages that you have observed for each transmission/communication medium?*

State-owned copper facility provides greater control over the repair process when necessary.

IX. *Are there specific disadvantages that you have observed for each transmission/communication medium?*

Our copper facility carries a large amount of data over a single cable with no backups. Any downtime, whether planned or unplanned is obviously a problem.

X. *Other comments:*

Please include us in the distribution of survey results.

THANK YOU AGAIN FOR YOUR ASSISTANCE AND EFFORT

COMMUNICATIONS MEDIA FOR FREEWAY SURVEILLANCE AND CONTROL

Agency: Texas Department of Transportation - District 02

Freeway Surveillance Site:
Tarrant County, Texas

I. *What technology do you use for freeway detection/information collection? (Please indicate all, such as CCTV, ramp metering with loop detectors.)*

1. Inductive Loop Detectors (ramp & mainline)
2. CCTV
3.

II. *How and where do you transmit the data/information collected for each type of technology listed above? (for example: 1. coaxial cable to central control center, 2. twisted wire pairs to controller at metering location.)*

Inductive Loop Data is transmitted via shielded twisted wire pairs.
CCTV Video is transmitted via multimode fiber optic cable.
CCTV Control is transmitted via shielded twisted wire pairs.
The origin/destination of all data is a satellite control center, on route to the central control center.

III. *Why did you select the media that you used to transmit data/information?*

Twisted wire pairs are a proven inexpensive technology which are easily expanded.
Multimode fiber optic cable provides the required band width for video and reduces or eliminates the signal loss and electro-magnetic interference common to coaxial cable and microwave transmissions.

IV. *What was the initial cost of installation and maintenance:*

Our projects, except for the CCTV project, were installed as components of reconstruction. Incorporation in reconstruction allowed us to implement the system, to date, for an average of 1.68% of the reconstruction costs. (see enclosed price sheets).
Maintenance costs unavailable - most items under warranty

(cont'd-over)

V. *Have you updated or improved your surveillance system, and particularly your data transmission/communications media?*

We have a project in design which uses multimode fiber optic cables for data transmission, via a T-1 channel, and video transmission.

VI. *What are your current costs for improvement and maintenance?*

See Question #IV

VII. *Have you had any specific problems with the media?*

Minor interference problems with twisted wire pairs.
Some modem failures
Contractor installation problems (poor splices, solder joints)

VIII. *Are there specific advantages that you have observed for each transmission/communication medium?*

Refer to Question III

IX. *Are there specific disadvantages that you have observed for each transmission/communication medium?*

Twisted wire pair cables are prone to electro-magnetic interference, and are unable to support video transmission.
Fiber optic cables have higher terminal equipment costs.

X. *Other comments:*

Our data communications emphasis is fiber optics for the future. We intend to use multimode cables for video transmission and local data circulation (field installations to satellite control center) and single mode cables for point to point communications (satellite to satellite and satellite to central)

We continue to investigate alternate technologies in all areas of the system (i.e. microwave transmission, video and sonic detection, ice detection, etc.)

THANK YOU AGAIN FOR YOUR ASSISTANCE AND EFFORT.

COMMUNICATIONS MEDIA FOR
FREEWAY SURVEILLANCE AND CONTROL

Agency:

TEXAS DEPARTMENT OF TRANSPORTATION

Freeway Surveillance Site:

SEE ATTACHED

I. What technology do you use for freeway detection/information collection? (Please indicate all, such as CCTV, ramp metering with loop detectors.)

1. CCTV
2. LOOP DETECTORS
3.

II. How and where do you transmit the data/information collected for each type of technology listed above? (for example: 1. coaxial cable to central control center, 2. twisted wire pairs to controller at metering location.)

SEE ATTACHED

III. Why did you select the media that you used to transmit data/information?

REQUIRED BANDWIDTH

IV. What was the initial cost of installation and maintenance:

PROJECT TO LETTING OCT. 1992

(cont'd-over)

V. *Have you updated or improved your surveillance system, and particularly your data transmission/communications media?*

NO, FIRST PROJECT

VI. *What are your current costs for improvement and maintenance?*

N/A

VII. *Have you had any specific problems with the media?*

N/A

VIII. *Are there specific advantages that you have observed for each transmission/communication medium?*

N/A

IX. *Are there specific disadvantages that you have observed for each transmission/communication medium?*

N/A

X. *Other comments:*

THANK YOU AGAIN FOR YOUR ASSISTANCE AND EFFORT.

(8-20-92)

COMMUNICATIONS MEDIA FOR FREEWAY SURVEILLANCE AND CONTROL

Agency:
CALIFORNIA DEPARTMENT OF TRANSPORTATION - CALTRANS
TRAFFIC SYSTEMS BRANCH
DISTRICT 7 - LOS ANGELES
120 SO. SPRING ST.
LOS ANGELES, CA 90012

Freeway Surveillance Site:
VARIOUS AREAS AROUND THE GREATER LOS ANGELES METROPOLITAN AREA - SEE ATTACHED MAP
1971 - 42 mile coverage
1993 - approximately 400 mile coverage
(Future) 1995 - 550 mile coverage

I. What technology do you use for freeway detection/information collection? (Please indicate all, such as CCTV, ramp metering with loop detectors.)

1. RAMP METERING WITH LOOP DETECTORS (INDUCTIVE LOOP DETECTORS ON EACH FREEWAY LANE)
2. CCTV - PRIMARILY USED FOR INCIDENT VERIFICATION
3. FIELD PERSONNEL (CALTRANS, CALIFORNIA HIGHWAY PATROL (CHP), FREEWAY SERVICE PATROL (FSP), in 2-way COMMUNICATION WITH THE TRAFFIC OPERATIONS CENTER (TOC).

II. How and where do you transmit the data/information collected for each type of technology listed above? (for example: 1. coaxial cable to central control center, 2. twisted wire pairs to controller at metering location.)

1. COAXIAL CABLE (CCTV) TO TOC.
2. TELEPHONE LINE (DEDICATED FOR DATA TRANSMISSION) TO TOC.
3. TWISTED WIRE PAIRS TO CONTROLLER (TYPE 170) AT METERING LOCATION
4. MICROWAVE TRANSMISSION (CCTV) TO TOC
5. FIBER OPTIC CABLE (CCTV & DATA) TO TOC

III. Why did you select the media that you used to transmit data/information?

1. TECHNOLOGY AT THE TIME OF DESIGN.
2. ESTABLISHED COST INVESTMENT IN EXISTING FIELD INFRASTRUCTURE
3. COMMUNICATION SERVICE AVAILABLE FOR LEASING AT TIME OF IMPLEMENTATION.

IV. What was the initial cost of installation and maintenance:

NOT ABLE TO QUANTIFY. CONSTRUCTION WAS GRADUALLY DONE OVER 25 YEAR PERIOD IN CONJUNCTION WITH OTHER FREEWAY PROJECTS. (ORDER OF MAGNITUDE - 10's OF MILLIONS OF DOLLARS).

V. *Have you updated or improved your surveillance system, and particularly your data transmission/communications media?*

YES, THE DISTRICT WILL BE UPGRADING THE COMMUNICATION MEDIUM, PRIMARILY TO FIBER OPTIC, VERY SMALL APERATURE TERMINAL SATELLITE (VSAT) AND MICROWAVE.

VI. *What are your current costs for improvement and maintenance?*

APPROXIMATELY $180 MILLION FOR DESIGN AND CONSTRUCTION OF AN UPGRADED TOS SYSTEM INCLUDING CCTV, COMMUNICATIONS, CMS, & HAR. OPERATIONAL COSTS ARE APPROXIMATELY $2.5 MILLION/YR PLUS ABOUT $2 MILLION/YEAR IN LEASED TELEPHONE CHARGES.

VII. *Have you had any specific problems with the media?*

SOME MICROWAVE TRANSMISSION PROBLEMS BECAUSE OF THE LOCATION OF THE OPERATIONS CENTER IN DOWNTOWN-LOS ANGELES (LINE-OF-SIGHT), UNRELIABLE LEASED LINE SERVICE, SLOW MAINTENANCE RESPONSE FROM LEASE CARRIERS, UNPREDICTABILITY OF LEASED LINE COSTS, CONSTRUCTION DISRUPTIONS OF TWISTED WIRE PAIR.

VIII. *Are there specific advantages that you have observed for each transmission/communication medium?*

YES, FIBER OPTICS WILL ALLOW MORE BANDWIDTH FOR DATA TRANSMISSION, REDUCE COSTS FROM LEASING PHONE LINES, IMPROVE EFFICIENCY OF SPACE, ALLOW MORE FLEXIBILITY FOR EXPANSION AND REDUCE MAINTENANCE COSTS.

IX. *Are there specific disadvantages that you have observed for each transmission/communication medium?*

FIBER OPTICS PRESENTS A SIGNIFICANT INITIAL COST FOR CONDUIT INSTALLATION AND THE DESIGN FOR A FULLY INTEGRATED AND OPERATIONAL COMMUNICATION NETWORK. SOME PROBLEMS WITH MICROWAVE FREQUENCY LICENSING & (LOS) LINE-OF-SIGHT REQUIREMENTS.

X. *Other comments:*

DETAIL OF FIELD SURVEILLANCE SIGHT & TIME RESPONSE.

THANK YOU AGAIN FOR YOUR ASSISTANCE AND EFFORT.

(8-20-92)