ITS TELECOMMUNICATIONS:

PUBLIC OR PRIVATE?

A COST TRADEOFF

METHODOLOGY GUIDE

INTELLIGENT TRANSPORTATION SYSTEMS
JOINT PROGRAM OFFICE

ITS Telecommunications: Public or Private?
A Cost Tradeoff Methodology Guide

Computer Sciences Corporation
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PB Farradyne Inc

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Section 1 - Introduction

1.1 Purpose and Scope

This cost Tradeoff Assessment Methodology Report outlines generic steps and strategy for analyzing the costs of obtaining telecommunications capacity to meet the requirements of jurisdictional ITS programs. It is a structured methodology that uses generally accepted engineering methods and follows Federal guidelines for performing cost-effectiveness analyses as defined in the Office of Management and Budget (OMB) Circular A-94, Revised October 29, 1992. A special focus has been placed on analysis of costs of owning versus leasing telecommunications for the ITS.

A base assumption for the use of this methodology is that the ITS for which telecommunications is needed exists either by mandate or public policy decision, and that the overall benefit to the public for any approach to providing telecommunications for the ITS is essentially the same.

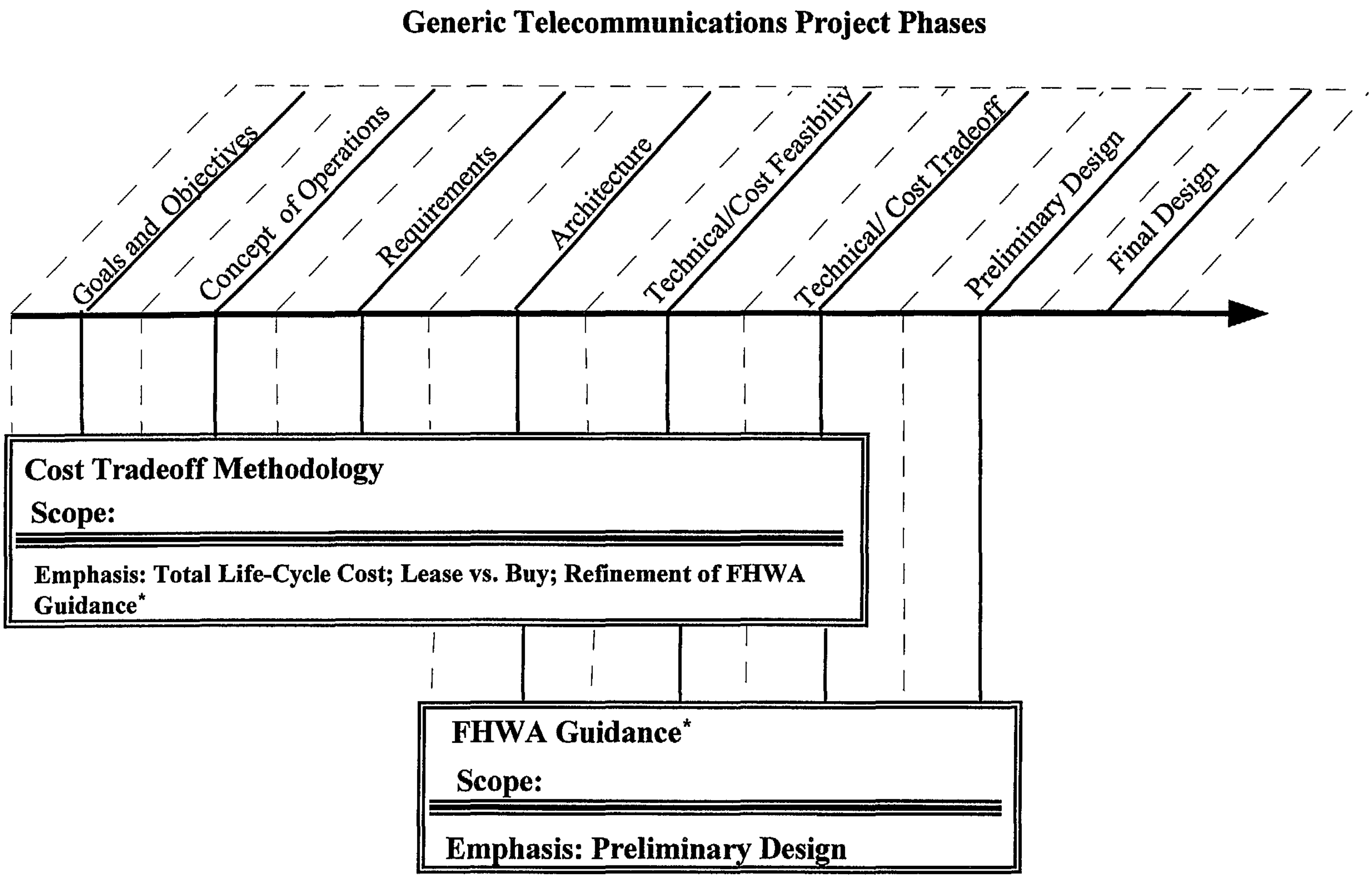
This methodology was used by the Maryland Department of Transportation's State Highway Administration in determining the best and most cost effective action for Maryland's Chesapeake Highway Advisories (for) Routing Traffic (CHART) ITS program.

Documentation of this methodology has been fully funded by the United States Department of Transportation (US DOT) in a public/private collaborative project with MDOT SHA, US DOT, Computer Sciences Corporation (CSC), and Parsons-Brinkerhoff, Farradyne, Inc.

1.2 Related Materials

Details on the Maryland study, CHART, and other related materials are available from both the US DOT ITS Joint Program Office and the Maryland State Highway Administration.

Some technical elements of this cost tradeoff assessment methodology overlap and expand on Federal guidance found in Chapter 11 of the *Communications Handbook for Traffic Control Systems,* report number FHWA-SA-93-052, April 1993. Figure l-l depicts high-level phases of an ITS telecommunications project. This cost tradeoff analysis methodology begins with the description of ITS goals and objectives and ends with recommendations for the most cost-effective telecommunications network architecture to be considered for implementation. Total life-cycle costs and lease versus buy alternatives are emphasized, and guidance that is presented in Chapter 11 of the aforementioned Federal Handbook is expanded upon.



* *Communications Handbook for Traffic Control Systems, Federal Highway Administration Report No. FHWA-SA-93-052 Chapter 11, Selection Techniques*

Figure 1-1. Scope of ITS Methodologies

The target environment for conducting tradeoff analyses using this methodology is the telecommunications infrastructure and capacity needed to communicate with ITS field devices from operational and management centers. Figure I-2 depicts the boundaries between the ITS telecommunications network, the field traffic management devices, and other ITS operational capability and shows which components of the system are considered communications-related and which are not by this methodology.

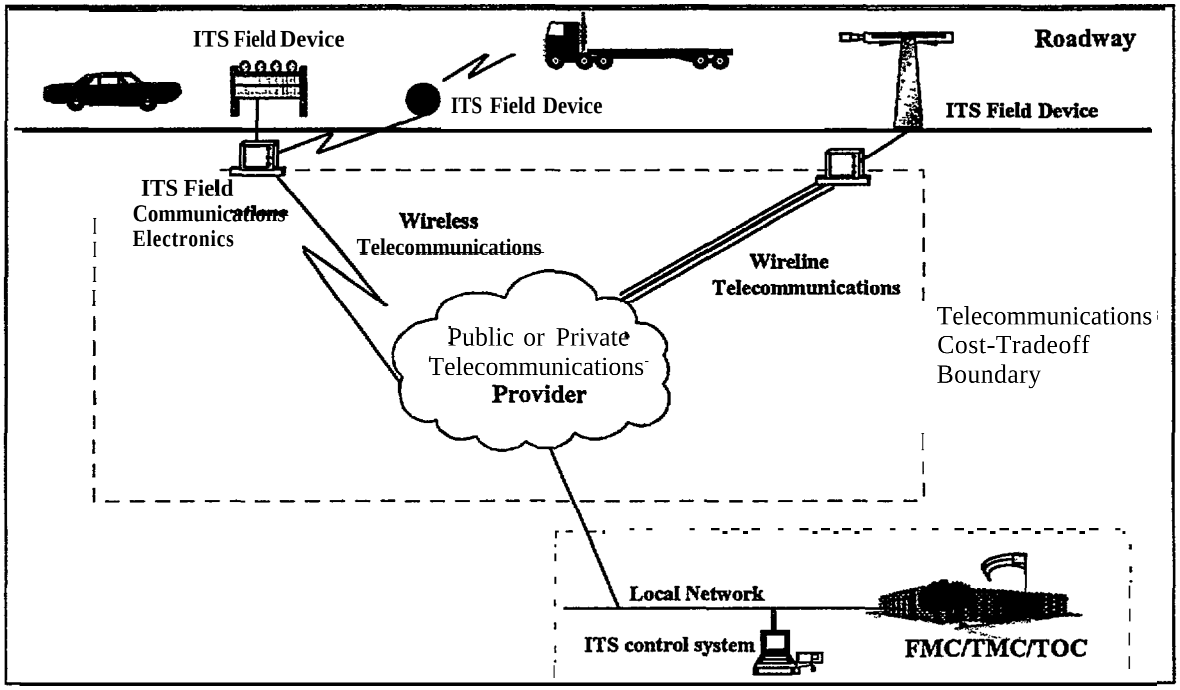


Figure I-2. ITS Telecommunications Network Boundaries

This ITS telecommunications cost tradeoff methodology is defined by two major processes:

- Systems Engineering
- Cost Analysis

Figure l-3 depicts each process and the high-level interaction between them. The Systems Engineering process: 1) develops ITS telecommunications goals, objectives, and requirements; 2) assesses available technology that can meet the requirements; and 3) provides for technical trade-off studies and produces alternatives.

The Cost Analysis process: 1) identifies the cost categories; 2) gathers cost data and develops the models to be used to calculate the costs for each alternative architecture; 3) calculates and analyzes the costs; and 4) investigates the sensitivity of the least cost alternative(s) to cost assumptions.

Figure l-4 provides a more detailed view of how such a study might be performed. A team is assembled that includes the transportation customer, various ITS stakeholders, and the telecommunications engineer or practitioner.

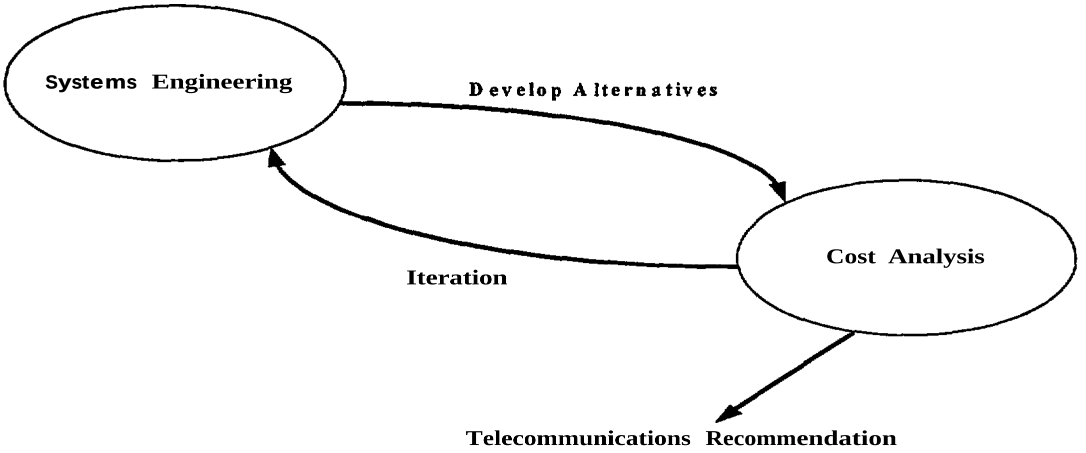


Figure l-3. High-Level Telecommunications Cost Tradeoff Processes

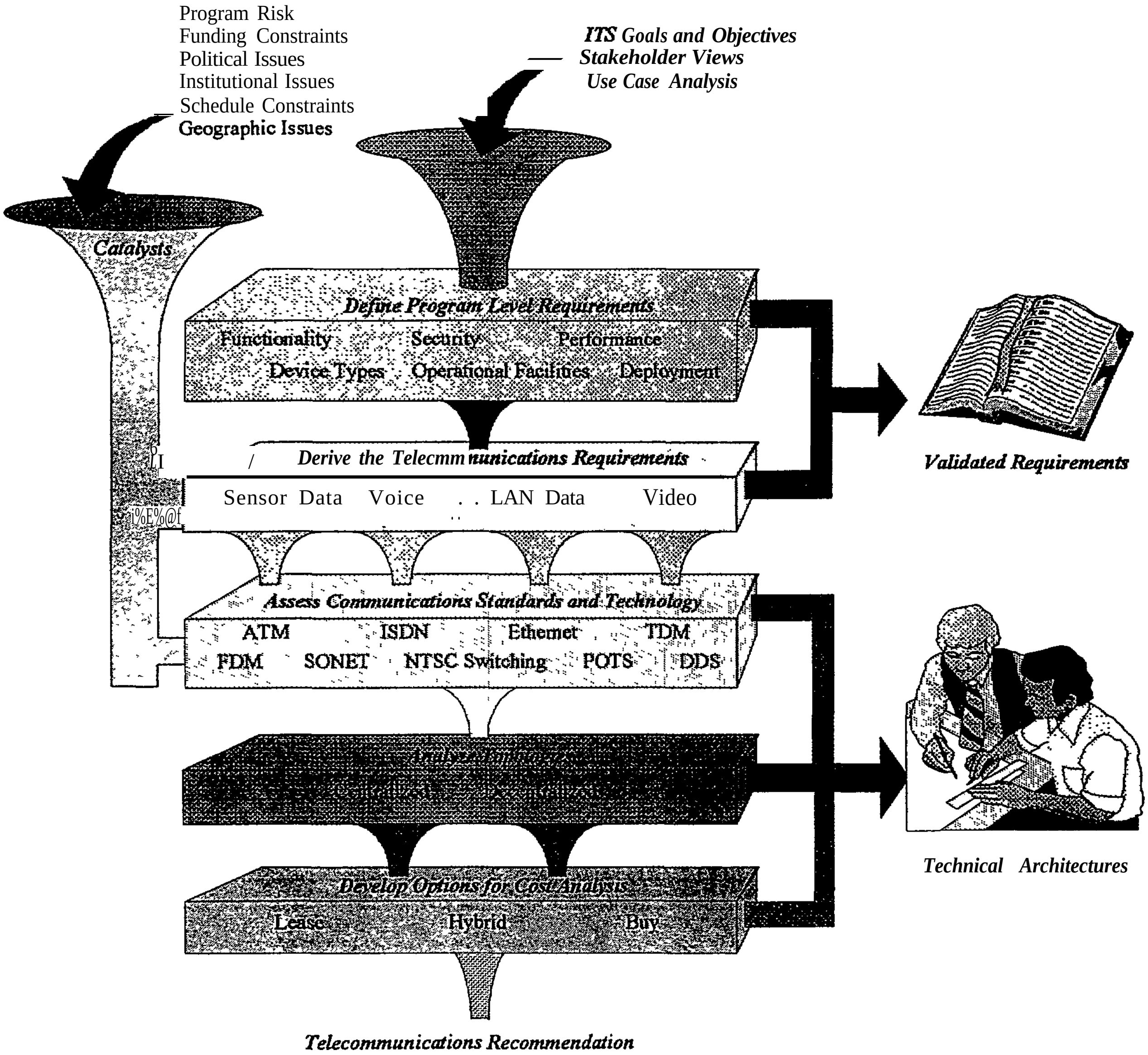


Figure 1-4. Cost Tradeoff Activities

The activities identified are:

- Defining the ITS program-level requirements
- Deriving telecommunications requirements
- Assessing technology and topology
- Analyzing options

Conceptually, the team begins at the top and proceeds to the bottom of the figure. The team accepts input and filters out the program-level functional, operational, and performance requirements.

Other issues and constraints are evaluated and all of the available information is used to derive technical requirements that the telecommunications engineer uses to develop technical tions engineer uses to develop technical alternatives. The derived requirements can cover all aspects of requirements and will include specifics for each of the telecommunications traffic the ITS system needs.

Finally, the alternatives are defined in terms of acquisition strategy for lease, buy, or elements of both if appropriate.

The processes and activities illustrated in Figures l-3 and 1-4 have been decomposed into the five-step methodology illustrated in Figure 1-5. Referring to the figure, these steps include:

1. Perform requirements analysis
2. Develop alternative technical architectures
3. Define costs
4. Calculate and compare option life-cycle costs
5. Perform sensitivity analysis

Each step is described in detail in the following sections of this methodology report.

Figure l-5 illustrates the relationship between the five-step methodology, the high-level cost tradeoff processes (Figure l-3), and the generic telecommunications project phases introduced in Figure l-l.

Note that in general, one step does not have to be completed before the next step begins. Note also that Step 4 for some technical architecture alternatives could terminate before completion. This would happen if the cost of one architecture is observed to greatly exceed the total cost of other options being analyzed. At this point, a decision could be made to stop the accumulation of all costs for the expensive architecture alternative.

1.3 Report Organization

The five steps comprising the tradeoff analysis methodology are described in detail in Sections 2 through 6, respectively.

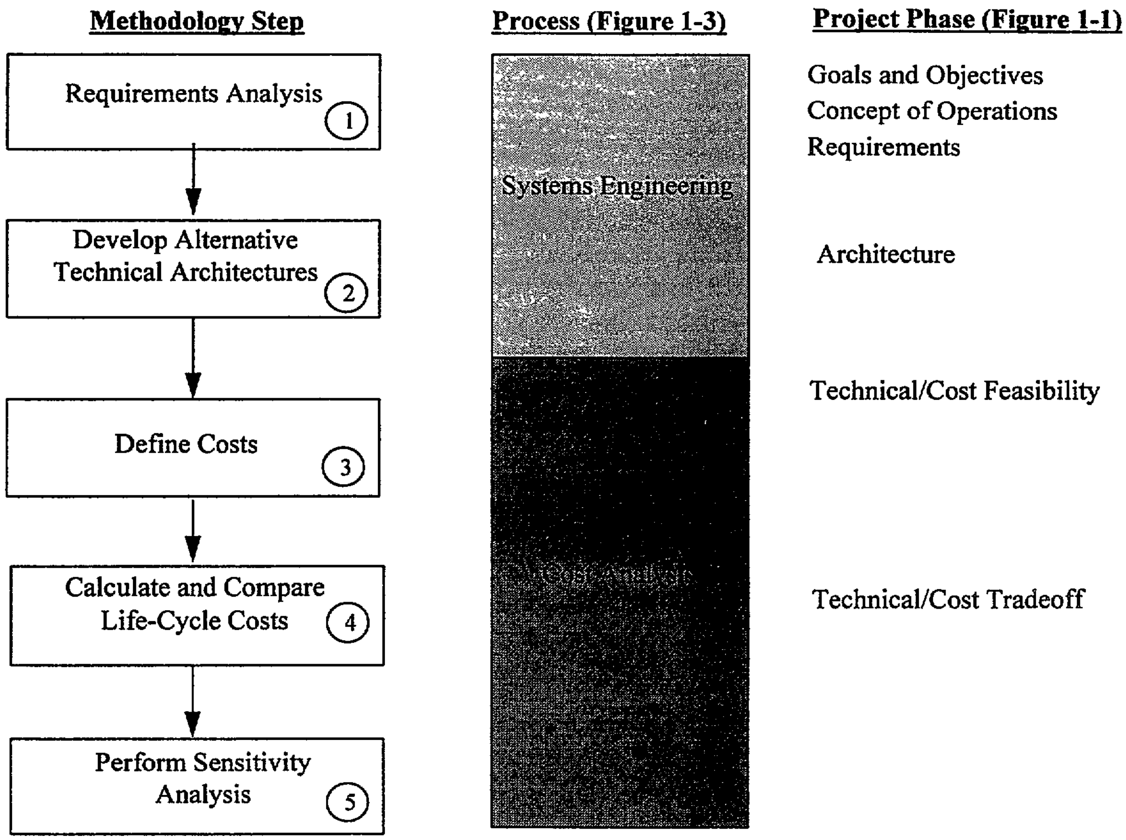


Figure 1-5. ITS Telecommunications Cost Tradeoff Relationships

Section 2 - Requirements Analysis

The most reliable and accurate way of performing cost tradeoff is to consider alternatives that accomplish similar objectives. In terms of a systems engineering approach for telecommunications, that means that each technical alternative must be based on the same set of requirements before the cost analysis can be meaningful.

Once generated, requirements should be validated so that some degree of consensus on behalf of stakeholders can be achieved. Requirements should also remain as constant as practical throughout the project to avoid developing the wrong solution or solutions for a moving target. This implies that they must be documented and managed over sometimes long periods of time. And finally, the requirements must eventually provide enough technical detail so that the communications engineer can develop reasonably detailed technical alternatives. Figure 2-l illustrates the recommended five-step requirements analysis methodology. Each step is described in detail.

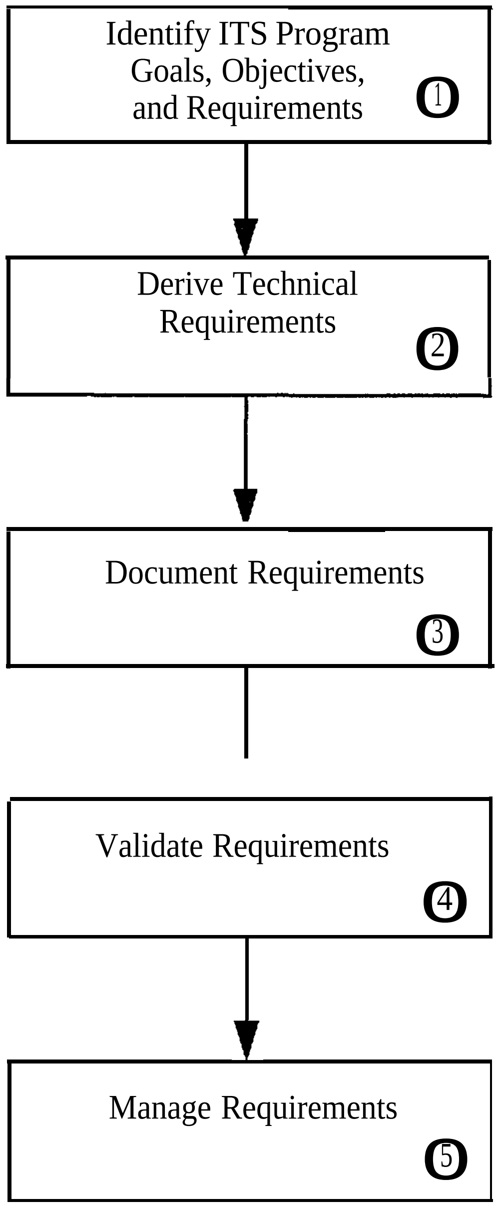


Figure 2-l. Requirements Analysis Methodology

2.1 Step 1: Identify ITS Program Goals, Objectives and Requirements

To be effective, requirements must of course reflect the goals and objectives of the ITS that the telecommunications network is intended to support. Requirements analysis for ITS telecommunications should then begin with the formulation of ITS goals and objectives by the ITS stakeholders. This is similar to the situation where engineering and construction of new roadways and bridges cannot begin until careful planning and studies identify who they will serve and where they will be. Only then can the nature of the vehicles expected to travel over them be identified. Likewise efficient telecommunications networks must be implemented with similar knowledge of who will be served and how by the ITS program. Only then can the characteristics of the data, video, and voice traffic that must be transported be identified with any certainty.

Figure 2-2 identifies three primary sources of ITS program information to be tapped:

- Historical information
- Technical exchange meetings
- Use Case analysis

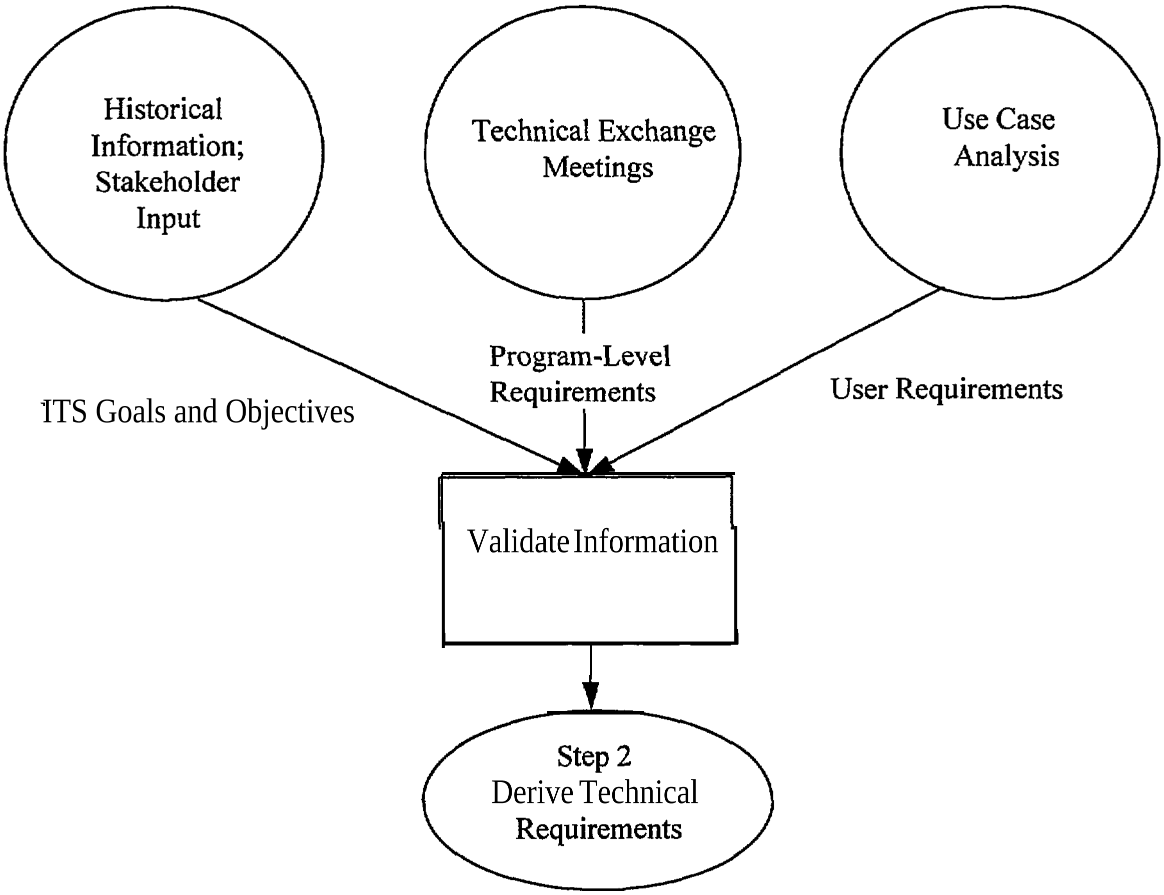


Figure 2-2. Identify ITS Program Goals, Objectives, and Requirements

2.1.1 Historical Information

A review of all historical information pertaining to the ITS program's goals and objectives is the starting point for the requirements analysis process. Information to be reviewed includes ITS program plans, feasibility studies, procurement documents, requests for information, technical presentations, related study reports, and minutes of meetings held. If a Benefit-Cost Analysis has been performed in support of the ITS program goals, this will an excellent source of information.

Specific to ITS applications, an important goal of the historical information review process will be the generation of comprehensive data tables. These tables will summarize the technical functions performed by all existing and future field devices to be included in the system; physical access requirements or constraints for each device type; the geographic location of and spacing between these devices; power requirements; environmental needs; and the timeline for device deployment.

If not already available, Geographic Information System (GIS)-based scaled maps and overlays illustrating facility locations, device placement on target roadways should be prepared. The deployment timeline information is also a very important driver for telecommunications. For example, the telecommunications needed (and hence the cost) to support the deployment of all planned devices starting in the first year of the life-cycle will certainly look different compared to one that supports a staggered device deployment strategy whether it is by roadway, priority of function or device, or any other means.

In addition to information review, other fact-finding should occur. The program's stakeholders should be interviewed face-to-face to obtain their assessment of the ITS program goals and objectives.

When the relevant information has been reviewed, a consolidated preliminary list of requirements should be prepared. Requirement statements should be written in precise and unambiguous terms. The preliminary list of requirements should then be validated by the program's stakeholders, users, and program office.

2.1.2 Technical Exchange Meetings

Diverse technical groups are available to provide input, guidance, and to assist in the identification and/or validation of ITS program-level requirements. These groups may comprise the stakeholders and typically include:

- Senior management
- ITS organizations
- ITS consultants
- Traffic engineers
- Construction engineers
- Information Systems/Information Technology (IS/IT) groups
- Users and Operators

Table 2-l summarizes the information and support that is likely to be obtained from these groups. As program-level

requirements are identified, the ongoing technical exchange meetings can be used as a convenient vehicle for formally validating them.

Table 2-1. Information Needed From Stakeholders

Group	**Type of Information/Support**
ITS Organizations	ITS program-level requirements.
ITS Consultants	Best practice for ITS systems.
Senior Management	Funding constraints and other institutional and organizational issues.
Traffic Engineers	ITS program-level requirements.
IS/IT Groups	Telecommunications and software requirements and constraints.
Users and Operators	System operation
Construction Engineers	Standards and practices for infrastructure.

2.1.3 Use Case Analysis

An ITS program can be successful only if it supports the needs of its users and operators. They are closer to the public than any stakeholder group and for this reason are a critical source of information. The manner in which the network will be used significantly affects the definition of candidate communications architectures. Use Case analysis is a method of determining the human activities involved in the ITS operation, thereby enabling information processing and telecommunications requirements to be derived.

As a first step, a set of Use Case scenario topics are defined. Table 2-2 lists examples of scenario topics that could be investigated.

Table 2-2. Candidate Use Case Scenario Topics

Use Case	Description
Incident Management	Incident detection, verification, response, clearance, & restoration.
Weather/Emergency Evacuation	Public awareness during a winter storm or other emergency.
Construction Management	Public awareness of construction site locations
Special Event Management	Public awareness of heavy traffic areas due to an event
Traffic Management	Traffic management during recurring, rush hour traffic.

For each Use Case scenario selected for analysis, ITS users and operators, their location, and associated devices and systems are identified. Users and operators are then asked, as a group, to define how the interaction between users and devices and systems should occur over time for each scenario. Specific questions to be answered include:

⇒ How are components of the ITS used?

⇒ What is the user's job?

⇒ What information does the user need?

⇒ With whom/what does the user interact?

In summary, Use Case analysis identifies the target functions or missions, captures the information required by each person to accomplish the function or mission, outlines necessary interaction with an information processing or technology system, and superimposes these along a timeline of events.

The Use Case analysis results can be effectively presented graphically in the form of data flows. These data flows can accurately describe a number of important requirements issues. Examples are how traffic, weather and pavement condition information will be consumed, how soon and how often it is needed, how closed circuit television (CCTV) will be used and what needs to be seen, what quality and timeliness of video is needed, which facilities require video monitoring and the number of monitors that will be viewed simultaneously in each facility, provisions for selecting images and arbitrating camera Pan/Tilt/Zoom (P/T/Z), and what will be viewed with cameras (e.g., incidents, road and/or weather conditions, maintenance objects, etc.).

Other Use Case scenarios can be defined to assist in developing strategies for degraded modes of operation and disaster recovery as needed. For example, the primary ITS control facility could become unavailable for many reasons, including loss of external communications, fire, sprinkler, flood, earthquake, or other hazard conditions making the building or parts of it inoperable. With the aid of Use Case scenarios, the allocation of functions to alternate facilities, the associated alternate routing of data, video, voice, and control over the telecommunications network to these facilities, and the allowable elapsed time between failure and the initiation of degraded operations functionality can be defined in a structured manner.

The documented results of each Use Case analysis should be reviewed and validated by the same personnel that provided the input data.

2.2 Step 2: Derive Telecommunications Requirements

For convenience, the telecommunications requirements are generally assigned to requirement types. Requirement types to be considered include:

1. Functional
2. Operational
3. Performance

Functional requirements identify what is to be done. Communications and information security requirements constitute a possible subset of functional requirements.

Operational requirements identify *who or what* performs the function, *where* the function is performed, *how many* perform the function, and *when* it is performed. Physical security and information security procedures requirements constitute a possible subset of functional requirements.

Performance requirements quantify measures such as *how much* and/or *how often,* and/or *how fast.* Reliability, Maintainability, and Availability (RMA) requirements constitute a possible subset of performance requirements.

The program-level requirements and the results of the Use Case analysis must be analyzed and translated into terms that communications engineers can use to derive technical architectures. Video, data, voice, LAN, RMA, and security are recommended architectural components that should be derived from the program-level requirements.

Video - Program-level requirements should identify the number and locations of the CCTV devices, video quality and motion requirements, and the locations of some but not necessarily all of the consumers of video. From the Use Case analysis results, the following communications requirements can be derived: the location of *all* consumers of video; the number of images to be viewed simultaneously at each location; all locations that will select and control the video, and the maximum number of images to be transmitted between any two facilities, and the directionality of video.

The video data rate (kilobits per second/megabits per second [Kbps/Mbps] per image) can be derived from the program-level video quality and motion requirements.

Data - Program-level requirements should identify those device types that will be polled for status and/or data, those that will automatically transmit data at pre-specified intervals, and those that will transmit data on an exception basis only. Through analysis, these requirements can be decomposed into derived communications performance requirements identifying: polling frequency; fixed data transmission frequency (where applicable), average and maximum exception-based frequencies (where applicable); format and size of the status and data messages for each device type; and the maximum allowable time to transmit each message. The message size and timing requirements can be further decomposed into transmission rates (Kbps, Mbps) per message.

Program-level requirements should also identify who (which location) will program the traveler information devices. Through analysis, these requirements can be decomposed into derived communications performance requirements identifying: the maximum frequency at which a given device will be programmed from each location; the format and size of the data messages exchanged for each device type; and the maximum allowable time to transmit each message. The message size and timing requirements can be further decomposed into transmission rates (Kbps, Mbps) per message exchanged.

Voice - Program-level voice communications functional and operational requirements can be decomposed into lower-level derived communications requirements. A program-level functional requirement could state that voice communications are required at certain types of device sites and ability to communicate with certain facilities or other field sites is needed. Derived telecommunications requirements for voice should include number of simultaneous calls, voice quality, store and forward functions and other voice related technical needs.

LAN - Since most ITS systems will include Workgroup or enterprise LAN infrastructure for hosting operator functions, LAN functional and performance requirements should be defined. LAN interconnectivity and interfaces, sizing for LAN-based storage, LAN bandwidth, client-to-server response time to access data and download applications may be pertinent.

RMA - Network availability, av, defines the percentage of time during a given period (day, week, month, year) that the telecommunications network is operational. At the requirements definition stage, availability may be stated as a goal, associated with some measure of overall effectiveness (e.g., how it would provide for the public safety). At the technical architecture development stage, availability can be estimated using representative configuration and equipment. It may not be possible to completely ascertain if the goal can be achieved until the preliminary design stage where actual configuration and equipment specifications are used.

Network reliability, maintainability, and availability are inter-related. Network reliability, expressed in terms of the mean time between failures (MTBF), defines how often, on average, the network fails. Maintainability, expressed in terms of the mean time to repair (MTTR), defines how fast, on average, the network is returned to operational status after a failure. Aailability is a function of the network MTBF and MTTR:

$$av = MTBF/(MTBF+MTTR).$$

The merits (including life cycle costs) of a particular network availability should be weighed against the predicted or historical availability of the traffic management devices. For example, assume that the availability goal is 99.9%, and an initial estimate of the network architecture's availability is 99.0%, and the average availability of devices is 99.2%. In this case, an increase in the availability goal might be contemplated. On the other hand, if the availability of the devices is 98%, any funds expended on enhancing the availability of the network may not be warranted since marginal gains at best would be accrued.

At the technical architecture development stage, network availability may be increased in several ways. Research can be broadened to identify candidate hardware components with improved MTBF and MTTR characteristics. Alternatively, availability can be increased by adding redundant hardware components in strategic locations, or making the system fault tolerant if necessary. Redundancy is achieved by having standby hardware and/or services available for use when needed in strategic locations within the network. When a failure occurs, a redundant system can be reconfigured within a finite period of time and a full or degraded mode operation can resume.

Fault tolerance is achieved by having redundant "hot backup" hardware and/or leased services available and ready for instantaneous switchover when necessary. With this type of configuration, switchover is transparent and no interruptions in service are encountered.

Both approaches to increasing system availability will increase life cycle procurement and operations and maintenance costs. Depending on the size and complexity of the network, a fault tolerant approach could have a prohibitive price tag. As noted above, the additional effectiveness must always outweigh the cost.

Security - Security requirements can be derived by analyzing the threats to the ITS telecommunications network that could impact public safety as a result of network failure and/or misuse. These threats could be in the form of sabotage, unauthorized network access and misuse, tapping and listening, modification, destruction, interception, and loss of data. Program-level functional security requirements can be decomposed into lower-level derived requirements. For example, after analysis of the program-level security requirements it may be deemed necessary to encrypt some data types. Telecommunications functional requirements to encrypt the data on the sending end and to decrypt the data on the receiving end would then be derived. If access to network resources is to be restricted to certain groups of individuals, then lower-level requirements would be derived. Derived requirements would state *how* the access is to be restricted *(e.g.,* use of specific workstations and/or assignment of user names and passwords). Derived operational requirements would state *when* actions are to be performed (e.g., require users to change passwords once per month).

2.3 Step 3: Document Requirements

Each program-level and derived telecommunications requirement should be assigned to the appropriate requirement type (e.g., functional, operational, etc.). For each type of requirement, . each high-level requirement should be assigned a unique identifier. A simple numbering scheme will generally be sufficient.

Each requirement statement should be concise as possible, and unambiguous. By convention, requirement statements are drafted using the verb "shall." A given requirement statement can be subdivided into two or more clearly-identified parts. Also, a requirement statement can reference a table or tables that contain detailed information. This is normally done to reduce the size and complexity of the requirement statement.

Any requirement that was derived from a high-level requirement should retain the identifier of the parent as part if its identifier. For example, assume that two performance requirements were derived from performance requirement 24. Identifiers 24.1 and 24.2 could be assigned to the derived requirements.

Table 2-3 is a table of hypothetical program-level requirements sorted by requirement type and identifier within the type. Note that functional requirement statements 3 and 4 each reference different external tables (Table 2-4 and 2-5, respectively). Note also that deployment requirements 35, 40, and 43, and operational requirement 96 all have multiple lettered parts.

Table 2-3. Hypothetical Program-Level Requirements

ID	Type	Requirement
3	Functional	Field traffic and roadway monitoring devices shall be deployed and perform the functions specified in Table 2-4.
4	Functional	Traveler information devices shall be deployed and perform the functions specified in Table 2-5.
7	Functional	Voice communications shall be provided at field device sites for use by field maintenance personnel.
35	Operational	Detectors shall be spaced along the roadway using the following guidelines: a. in urban areas with non-recurring congestion, l/2 mile b. in urban areas with recurring congestion, 1 l/2 miles c. in rural areas, greater than 1 l/2 miles.
40	Operational	Devices to be deployed in future years shall be located geographically in accordance with the most current revisions of the following maps and associated overlays: a. for roadway X, refer to map 24 b. for roadway Y, refer to maps 16 and 32 c. for roadway Z, refer to maps 47,53, and 62.

Table 2-3. Hypothetical Program-Level Requirements (Cont'd)

ID	Type	Requirement
43	Operational	Devices shall be deployed in the field in accordance with the following scheduling guidelines: a. priority 1 devices, within one year b. priority 2 devices, within 1 to 3 years c. priority 3 devices, between 3 and 7 years.
78	Operational	Overhead Traffic Detector (OTD) devices will report on an exception basis.
83	Operational	Road and Weather Information Systems (RWIS) devices will be polled for data.
96	Operational	The following facilities shall receive ITS video data a. Traffic Operations Centers (7) b. Freeway Management Centers (2) c. administrative facilities (15) d. maintenance facilities (26) e. other jurisdiction XYZ 1. facility #3 2. facility #7 3. facility #15

These techniques aid in reducing the total number of requirement statements without impacting critical information.

Table 2-4 is a table of hypothetical derived telecommunications requirements. Referring to the table, functional requirements 4, 5, and 7 are examples of lower-level requirements that are derived from a high-level requirement.

The initial complete lists of program-level and telecommunications requirements are terrned the Preliminary Requirements Baseline.

2.4 Step 4: Validate Requirements

The Preliminary Requirements Baseline should be submitted for review by representatives of the appropriate funding, operating, and user organizations. Following the incorporation of review comments, the Final Requirements

Baseline should be formally published and distributed.

2.5 Step 5: Manage Requirements

As noted earlier, some requirements can be expected to change as the program matures and responds to external events.

If it becomes necessary to modify or delete any requirements in the current version of the Requirement Baseline, or add new requirements, a revised baseline should be published, validated, and distributed.

Tab/e 2-4. Hypothetical Derived Telecommunications Requirements

ID	Type	Requirement
2	Functional	The network shall be capable of monitoring the status of field and roadway monitoring devices.
3	Functional	CCTV images shall be digitized and compressed for transmission.
4	Functional	The network shall be capable of selecting, viewing, and P/T/Z control of connected CCTV devices.
4.1	Functional	The Traffic Operations Center shall be capable of selecting, viewing, and P/T./Z control of any CCTV connected to the network
4.2	Functional	The following facilities shall be capable of selecting, viewing, and P/T/Z control of CCTV devices within their respective areas of responsibility: a. administrative facilities b. maintenance facilities
5	Functional	The network shall support the handoff and arbitration of P/T/Z control of CCTV devices.
5.1	Functional	The Traffic Operations Center shall be capable of handoff and arbitration of P/T/Z control of all CCTV devices.
5.2	Functional	The following facilities shall be capable of handoff and arbitration of P/T/Z control of CCTV devices within their respective areas of responsibility: a. administrative facilities b. maintenance facilities

Table 2-4. Hypothetical Derived Telecommunications Requirements
(Cont'd)

ID	Type	Requirement
7	Functional	The network shall support the following functions associated with the VMS, TAR, and Dynamic Traveler Alert Sign devices: a. arbitrate access b. programming c. auditing
7.1	Functional	The Traffic Operations Center shall program all VMS, TAR, and Dynamic Traveler Alert Sign devices.
7.2	Functional	The maintenance facilities shall program the VMS, TAR, and Dynamic Traveler Alert Sign devices within their areas of responsibility.
3	Performance	CCTV images shall be compressed to a frame rate of 15 frames per second and transmitted at a rate of 384 Kbps.
4	Performance	The network shall distribute CCTV images for simultaneous viewing at the designated facilities: 1. Traffic Operations Center - 16 images from any CCTV site, with no more than 7 from any one administrative facility 2. administrative facilities - 7 out of the total number of CCTV sites within the area of responsibility 3. maintenance facilities - 1 out of the total number of CCTV sites within the area of responsibility 4. other jurisdiction ABC - 1 image.
111	Performance	ODT controllers shall be polled for status (up/down) at a rate of up to once per minute.
112	Performance	ODT data records are 50 K bytes long.
2	RMA	The network shall achieve an availability of 0.98.
6	RMA	The network mean time to repair (MTTR) shall not exceed 3.0 hours.
4	Security	Network access shall be controlled by assigned user names and passwords.

Section 3 - Developing Alternative Technical Architectures

Key to the lease versus own issue is first knowing what kind of telecommunications network is needed regardless of how it is obtained. A solution that is either over engineered or under engineered will never completely satisfy all stakeholders from cost or technical standpoints. Lease or own should be secondary to describing the telecommunications approach that best meets the documented need. Once this is done, how to achieve the desired solution at the lowest possible cost should be considered with respect to lease versus own.

Key to finding the right technical solution at the lowest cost is the development of multiple alternatives. The correct number of alternatives to develop depends on the specific issues and constraints present, as well as time and funds available for the project. A minimum of three to four alternatives with substantial technical differences will increase the chances of finding the best alternative. Consideration of alternatives based on: 1) the commercial infrastructure in place, 2) an optimal build technique, and 3) combinations of the two, will increase the chances of finding the most cost-effective alternative.

The recommended approach to developing technical alternatives is based on the concept of "technical architecture." A technical architecture includes enough technical detail to allow life-cycle costs to be accurately predicted while still allowing the communications designer flexibility in choosing specific products and services for implementation later in the project.

The level of technical detail included is a compromise between the time spent and the risk of severely under estimating or overestimating costs. For a complex statewide telecommunications network to support ITS functions, devices, and systems, a period of 4 - 6 months should be sufficient for developing several technical architecture alternatives.

Although cost is the major focus of this methodology, once viable alternatives are identified and developed, they can be evaluated with regard to several subjective factors in addition to cost. These factors include schedule risk that will be incurred as a result of implementing each alternative, relative ease of implementation, ease of use and maintenance, security, overall capacity considerations, and technical maturity and obsolescence factors as well as other subjective engineering criteria.

This section defines the recommended approach to developing technical alternatives that can be used to accurately predict the life-cycle cost of deploying and sustaining a complex ITS telecommunications network through lease, own, or lease/own hybrid approaches.

3.1 Characteristics of a Technical Architecture Alternative

An alternative technical architecture can be completely described by four characteristics:

- Standards and Technology

- Physical Topology
- Representative Building Blocks
- Technology Implementation Strategy as shown in Figure 3-1

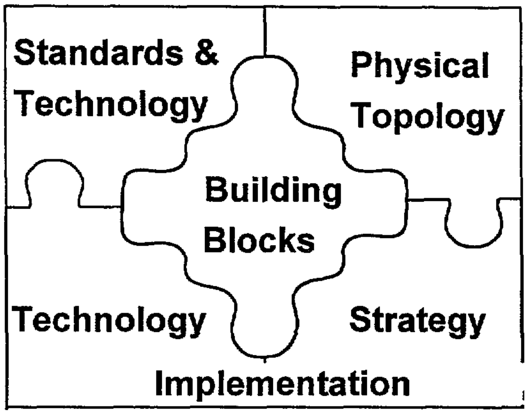


Figure 3-1. Characteristics of Technical Architecture

An alternative technical architecture can begin to be described by two simple characteristics:

Standards & Technology - the profile of technologies, and the national, international, de-facto, or de jure standards that describe them that are currently available to meet functional and performance needs. The pool of available technologies is drawn from and a limited number is incorporated into the technical architecture as necessary. Several architectural components that are produced by the requirements process should be addressed by specific technologies:

- Sensor data transport
- Connectivity to field traffic management device controllers
- Video transmission
- Video compression and digitization
- Video switching
- LAN interconnectivity
- Voice transmission

Table 3.1 shows examples of applicable technologies that can describe each architectural component of the telecommunications network.

Table 3-1. Telecommunications Technologies

Architectural Component of the Telecommunications Network	Applicable Technologies
• Sensor data transport • Connectivity to field traffic management device controllers	• POTS • DDS • ISDN • MULTIDROP DDS • MICROWAVE • INFRARED • CELLULAR
• Video transmission	• NTSC ANALOG • T1/TDM • T3/ TDM • FDM • SONET/SDH • ATM
• Video compression and digitization	• ITU-T H.320 (H.261) • MPEG • M-JPEG
• Video switching	• NTSC ANALOG • TDM • ATM • SONET • DCS
• LAN inter-connectivity	• ETHERNET • FRAME RELAY • SMDS • FDDI • ATM • SONET
• Voice transmission	• TDM • FDM • SONET • ATM • T1/TDM • T3/TDM

Each technology or combination of technologies should be evaluated to determine if and how well it meets the functional and performance requirements for each architectural component and what the cost impacts of using a particular technology will be over the life cycle compared to other technologies. Relative advantages and disadvantages should be stated and evaluated with respect to specific technical criteria. Evaluation of the governing standard should be performed to measure the degree of technical maturity and interoperability between vendors providing the product or service that implements the technology.

Physical topology - topology describes the relative placement and interconnectivity strategy for linking all the necessary components of the ITS network. This includes field traffic management devices and communications electronics, telecommunications network switching equipment, computer systems, and operations personnel at the management facilities together. Two basic topologies should be considered: all communications from field locations centralized on a single site, and communications decentralized utilizing hub locations other than the central site. For a decentralized topology, the definition of a telecommunications backbone and feeder links should be performed.

Figures 3-2 and 3-3 show conceptual views of centralized and decentralized topologies. Table 3-2 shows advantages and disadvantages of telecommunications network topologies.

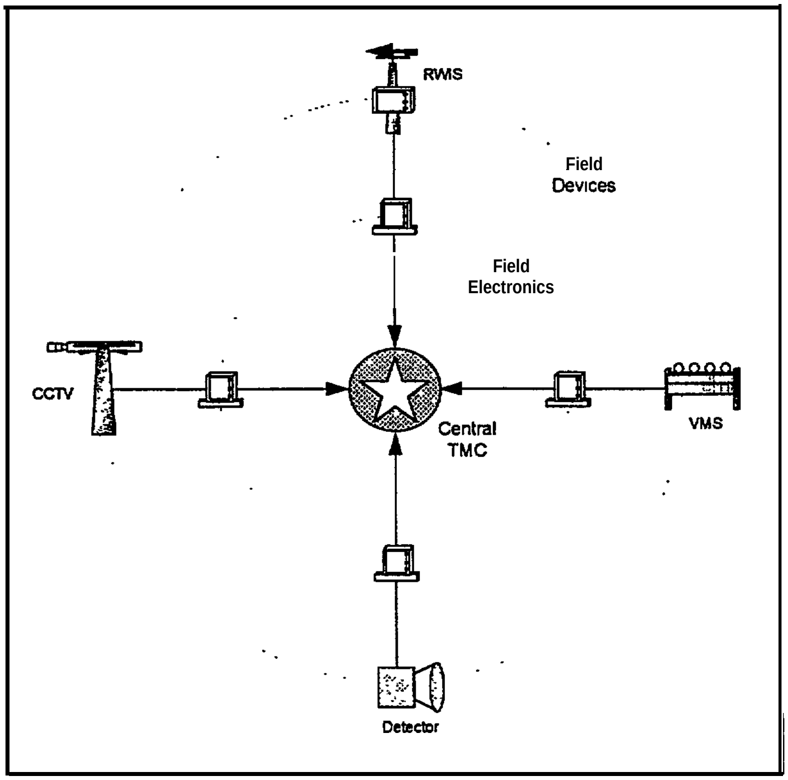


Figure 3-2. Centralized Topology

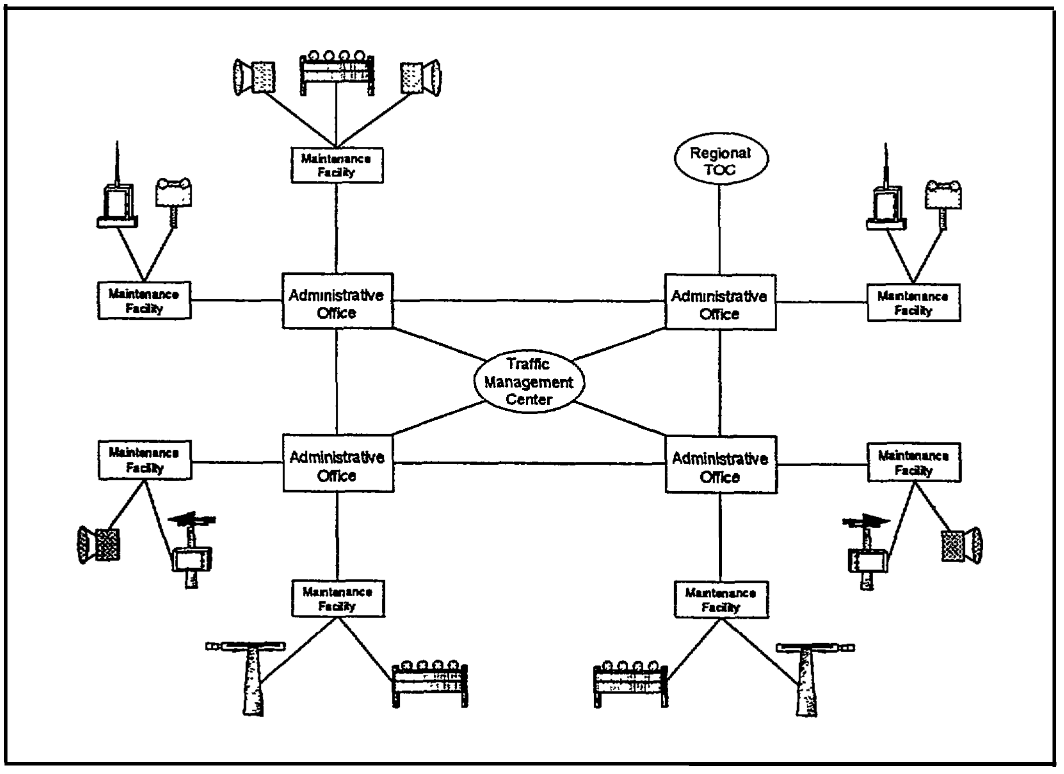


Figure 3-3. Decentralized Topology

Table 3-2. Advantages and Disadvantages of Network Topologies

Topology	Advantages	Disadvantages
Centralized	• Easier to maintain • Conceptually simple configuration • Maximum amount of control for central site	• Single point of failure concerns • More capacity, connections, and circuit miles required if leased • Excessive amount of equipment at central site • All video must be brought to central site for switching • Not scalable • Not accessible from other sites
Decentralized	• Scaleability • Shortens higher bandwidth circuits and avoids long-distance tolls if leased • Can be accessed from multiple sites	• Higher technical complexity

An estimated performance load for each resulting physical link further describes the technical architecture's topology and allows the alternative to be quantified, compared, and for costs to be predicted.

To achieve a greater level of detail and to increase the accuracy of the cost comparison, a third characteristic, that of defining representative building blocks, can be added to the development of alternative technical architectures.

Representative building blocks - these include the actual or planned field traffic management devices and associated communications electronics, and representative telecommunications network transmission and switching equipment, computer hardware and software, and wireline and wireless communications transmission capacity that are capable of implementing the technologies that are selected. Table 3-3 provides examples of building blocks for each architectural component of the telecommunications network.

Table 3-3. Example Telecommunications Network Building Blocks

• Field Traffic Management Devices	• Traffic device controllers (e.g., 170E, 2070, etc.) • CMS/VMS • RWIS • TAR/HAR • CCTV • RADAR
• Communications	• Traffic device controller communication adapters • Multiplexers • Channel Banks • Cell Switches
	• Video Switches • CODECs • Camera Control Units • Cross Connect Switches • Modems • Line Drivers • Routes • Personal Computers • Workstations • Cabling • Repeaters • Splitters • Transceivers

For a complete description of the technical architecture, a fourth characteristic, that of development of a technology implementation strategy, can be added.

Detailed Technology Implementation Strategy - Used to validate effective and appropriate use of the selected technologies in a technical architecture alternative, this aspect of analysis describes how particular facets of each technology are incorporated into the telecommunications network. Critical interfaces to the telecommunications network from ITS field devices and the control system's computers and LANs are defined. Table 3-4 provides other Technology Implementation examples that should be considered during alternatives development. All may not be pertinent depending on the choice of technologies for the architecture alternatives.

Table 3-4. Examples of Technology Implementation Strategy

- Incorporation of redundancy and fault tolerance into the telecommunications architecture
- Virtual and physical channelization of switched facilities (e.g., TDM, ATM, SONET switches and/or facilities)
- How carrier circuits might be aggregated at central office or other provider sites
- The application of available Quality of Service and traffic categories
- How the network will be managed (e.g., provisioned, diagnosed, and restored to and from built-in redundant capacity)

3.2 Development of Alternative Technical Architectures

The development of alternative technical architectures should be influenced by two major factors. First are the documented and validated requirements. The technical architecture step transforms both the stated and derived requirements into something that can be assigned a cost for comparative analysis. Second are the inevitable issues and constraints that are present internally and externally to the state or local government agency charged with deploying the telecommunications network.

Issues and constraints vary with jurisdiction but among those that can influence telecommunications technical architecture and should be considered include:

Funding - what level of funding is available for the ITS program? What percentage of this has been allocated for the telecommunications network? For the network's operations, maintenance, and sustaining engineering.

Schedule - what are the schedule drivers for deployment of the telecommunications network?

Institutional/political - what are the relevant institutional issues that impact how the telecommunications network will be deployed? Are there one or more existing or planned future telecommunications networks that link some or all of the facilities or geographic areas to be interconnected by the ITS network? If so, can overall life-cycle costs be reduced by integrating these networks into the ITS network? Do other agencies or jurisdictions have sources of ITS-related video or data that are consistent with the goals and objective of the ITS program? If so, is it technically feasible to collaborate with these agencies? What is the net life-cycle cost difference of such collaboration? Is there existing or planned future wireline or wireless telecommunications transmission capacity that could be made available through either a barter agreement or cash through a monetary agreement for right-of-way? If so, is it technically feasible and cost-effective to utilize this capacity? Is dark fiber available? If so, what is the net life-cycle cost difference of integrating it into the telecommunications network?

Geographic - Does the ITS device population density profile within the jurisdiction or the jurisdiction's actual geography and/or population profile drive meaningful options on lease/buy hybrids that may yield lower costs?

Another key factor that should be considered during technical architecture alternatives development is the existing or planned information systems architecture. Analysis of where the data should be received, stored and processed in order to minimize the communications load, optimize utilization, minimize initial and recurring cost, and increase system accuracy, responsiveness, and performance is a critical dependency to the telecommunications network's architecture and should be carefully examined.

At a more detailed level, the definition of communications device spacing or clustering along roadways and/or around provider points-of-presence should be undertaken with the goal of minimizing telecommunications cost,

3.3 Products of the Technical Alternatives Development

The products of alternative technical architecture development should include at a minimum, a strawman configuration drawing for each alternative. An itemized list of representative building blocks that comprise the alternative's implementation in the cost model should also be produced. A strawman drawing is shown in Figure 3-4.

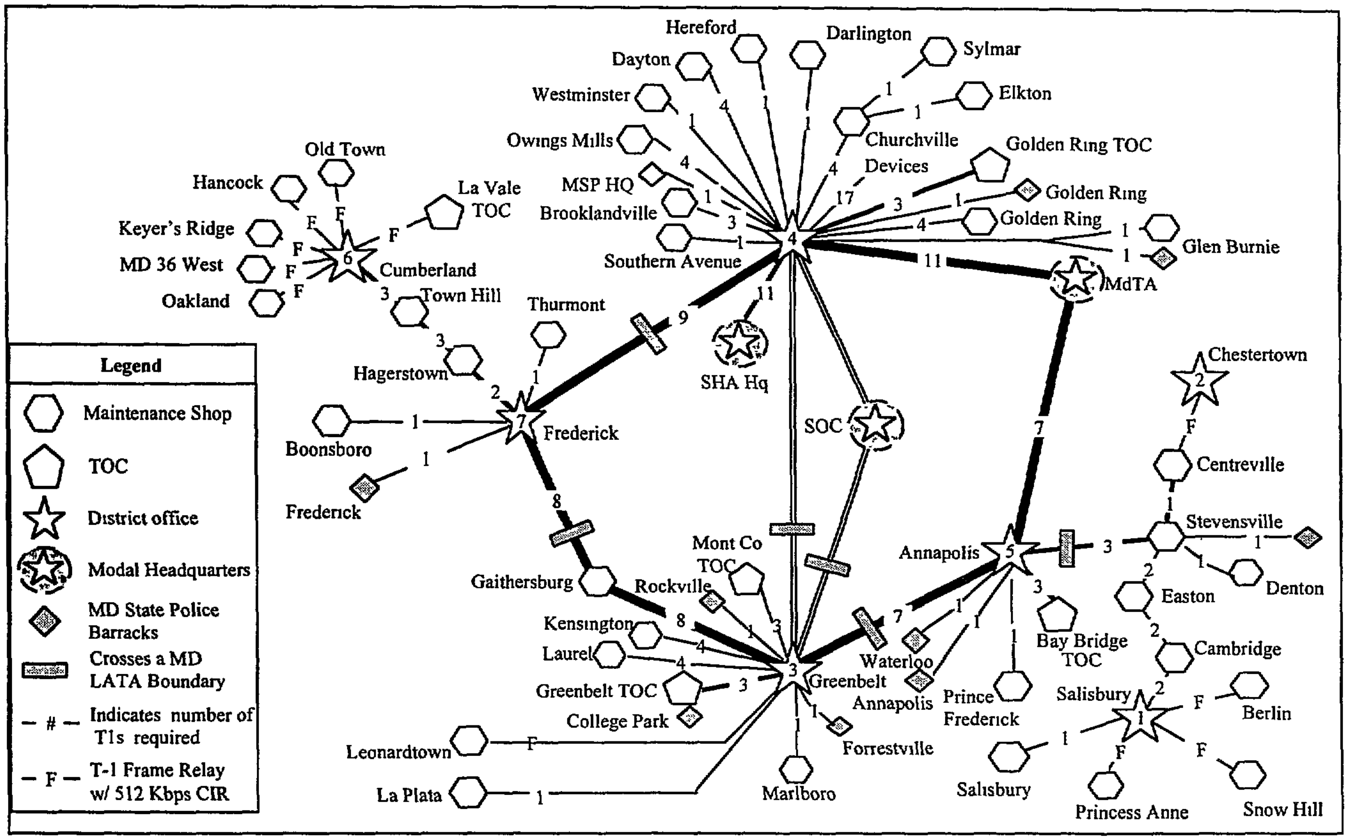


Figure 3-4. A Telecommunications Network Alternative for Maryland's CHART

Section 4 - Define Costs

The ultimate focus of cost tradeoff analysis is the development of life cycle cost models for communications architecture options to support management decision making. Considerable effort should be allocated to the definition and a strategy for accumulation of component costs for the communications architecture options that have been identified.

Communications-related costs can be grouped into five cost elements including:

1. **Construction** - roadside enclosures and cable plant installation (where appropriate) for both build and lease portions of all options.
2. **Leased circuits** - installation of commercial telecommunications lines and recurring service and maintenance of these lines.
3. **Communications equipment** - representative electronics and communications hardware and computers that would support data, video, and voice transport.
4. **Communications OAM&P labor** - operations, administration, maintenance, and provisioning. Full-time and on-call labor to operate, control, configure, administer, troubleshoot, provide spares, and repair communications electronics and hardware.
5. **Communications software - software** to manage the collection, delivery, and distribution of CHART data and information.

Note that in some applications, the basic strategy used for accumulation of component costs can be a top-down approach starting with those that would most likely comprise the largest share of the total cost for each architecture option. Based on this rationale, estimates for one or more "key" cost elements, e.g., construction and leased circuit costs, might be identified and accumulated first for all options, followed by communications OAM&P labor costs, communications equipment costs, and finally communications software costs.

By using this strategy and order of accumulation, if any one option accumulated all components of cost and results in a total cost less than another option whose costs are not fully accumulated, accumulation of further costing may not be needed for the higher cost option.

Sections 4.1 through 4.5 decompose each cost element into cost parameters and present the potential sources of cost information.

4.1 Construction Costs

The construction cost element includes:

1. Backbone infrastructure
2. Device connections
3. Environmental enclosures

Backbone infrastructure and device connections are applicable to the build and hybrid acquisition options. Environmental enclosures can be found for all acquisition options, including lease.

Backbone infrastructure generally consists of copper or multiple strand fiber optic cable installed via a multiduct conduit by various methods and related support equipment and facilities; these are necessary to support junctions and splices to the backbone trunk fibers and to provide maintenance access points. These related components include manholes, handholes, and junction/splice blocks which are placed in protective enclosures.

Device connections join roadside devices to a backbone. A feeder cable needs to be provided from the device site to the nearest POP where it can be spliced into one of the backbone's strands. This is demonstrated in Figure 4-1. In general, the trench will have a perpendicular (or cross-road) run to reach the backbone and then will traverse the road to reach the POP. Eventually, as devices are connected along the roadway, all of the free strands will be used up. When this occurs, the devices need to be hubbed into the network using electronics (e.g., multiplexers housed in an environmental enclosure) in order to free up the strands again.

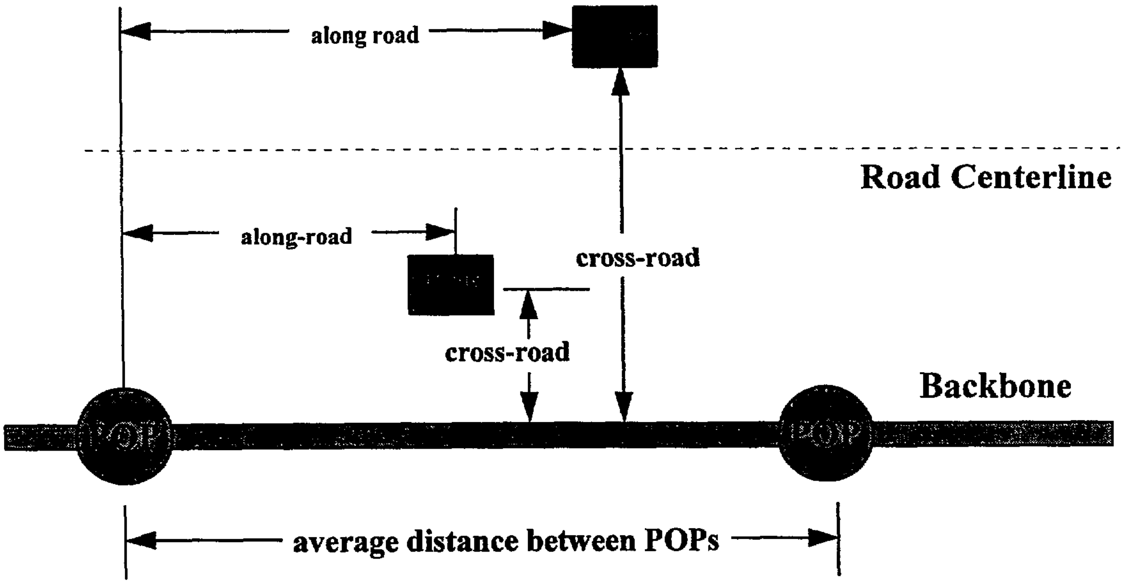


Figure 4-1. Roadside Device Connection

Environmental enclosures are required to protect non-ruggedized (or hardened) network equipment in the field from the elements and temperature extremes.

For the build and hybrid classes of network architecture, the number of environmental enclosures required to house equipment along each road segment where fiber optic cabling is installed is determined by what type of equipment is used and how the individual fiber strands are consumed by connections. Note that some ruggedized electronics capable of supporting camera site connectivity (e.g., CODECs) are currently on the market. Successful field testing of this equipment by multiple vendors would obviate the need for environmental enclosures at camera sites.

A recommended methodology for developing the life-cycle construction costs is presented in Section 4.1.1. Construction cost parameters are summarized in Section 4.1.2.

4.1 .1 Construction Cost Development Methodology

The following three-step process is recommended to efficiently develop construction cost estimates. The sequence is:

1. Identify applicable construction methods and parameters.*
2. Develop engineering parameters and costs.
3. Derive schedules
4. Calculate life-cycle construction cost for all options.

* These steps will be performed in parallel

Identify applicable construction methods and parameters - The communications backbone can be constructed using one or more methods that are usually site specific to provide a low cost, fully engineered communications solution. Some of these methods are:

- Backbone trenched with cable in a duct
- Backbone plowed with direct buried, armored cable
- Backbone jacked (bored) with cable in a duct
- Backbone directional drilled with cable in a duct
- Backbone trenched with direct buried, armored cable
- Backbone placed aerially with lashed or figure 8 cable
- Backbone placed on a longitudinal bridge structure with cable in a duct

The construction methods to use, the percent of the total construction anticipated for each method, and the average productivity rate (miles per month) for each method must be identified. Other engineering parameters such as the desired spacing between manholes, the type of conduit, and in the case of fiber optic backbones, fiber optic cable mode and strand count must also be determined.

The locations of device sites relative to the backbone segments and points-of-presence (POPS) to which they will be connected are also needed.

Develop engineering parameters and costs - The construction methods to use and the percent of the total construction anticipated for each method can be obtained in-house and/or from engineering consultants. These sources can also provide other important engineering parameters such as the desired spacing between manholes, the type of conduit, and fiber optic cable mode and strand count.

The locations of device sites relative to the backbone segments and POPs to which they will be connected can be obtained from ITS program-supplied Geographic Information System (GIS)-generated maps. Ideally, these maps will be available in digital format. If so, along-road and cross-road distances from each device site to the backbone POP can be calculated automatically. An overall average along-road and cross-road distance for each road segment can then be calculated and used for costing purposes.

If digitized maps are not available, then support from in-house engineering personnel and/or engineering consultants may be needed to select "not to be exceeded" estimates of the device connection metrics.

The locations of the facilities to be connected to the network should be known exactly, with the possible exception of the location of the POPS for external interfaces. This information will be established through coordination with the external organizations.

Unit cost information must be obtained for all applicable construction services and hardware. These items include:

- Backbone construction ($/mile for each construction method used)
- Furnish and install (F&I) manholes, handholes, fiber optic junction/splice blocks, and environmental enclosures ($/unit)
- F&I conduit ($/foot for each type of conduit used)
- F&I cable ($/foot for each type of cable used) [for fiber optic backbones, mode-strand count combinations]
- For fiber optic backbones, F&I fiber optic converters ($/unit).

Potential sources for the required unit costs include in-house and/or consultant engineering personnel, bid pricing and historical project data, and vendor quotations.

Derive schedules - Construction schedules will be coupled with the ITS program schedules. Ideally, preliminary construction start and end dates will be known for each road segment. Where this is true, the planned percentage of construction to be completed per life-cycle year will be known. If either the planned construction start or end dates are not known, the project duration can be estimated by assuming construction productivity rates (e.g., average miles per week or month) based on the planned construction methods. Given the project duration, the unknown start or stop date can then be derived.

Calculate life-cycle construction costs for all options - The backbone infrastructure cost is the total of the cost incurred by the:

- Construction methods ($/mile * number of miles for each construction method used)
- Cable F&I cost ($/foot * number of feet[including slack])
- Conduit F&I cost ($/feet * number of feet)
- F&I cost for all of the related support components including manholes, handholes, and junction/splice blocks ($/unit * number of units for each component).

The device connection cost is the total of the cost incurred by the:

- Construction methods ($/mile * number of miles for each construction method used).

- Cable F&I cost ($/foot * number of feet[including slack])
- Conduit F&I cost ($/feet * number of feet)
- F&I cost for fiber optic converters ($/unit * number of units).

The environmental enclosure F&I cost is the product of the enclosure unit cost and number of units purchased.

The costs for each construction project can be distributed across the life cycle using the schedule information described in the previous step. The total cost life-cycle cost of the construction element is the sum of the backbone infrastructure, device connection, and environmental enclosure life-cycle costs for all construction projects.

4.1.2 Construction Cost Parameter Summary

4.1.2.1 Backbone Infrastructure Cost Parameter Summary

Infrastructure cost parameters common to all fiber optic backbones include:

- Applicable construction methods and unit costs (e.g., per mile) for these methods
- Average productivity rate for each construction method used
- Communications handhole F&I unit cost
- Manhole F&I unit cost
- Cable splice block with enclosure F&I unit cost
- Cable F&I unit cost
- Conduit F&I unit cost.

Cost parameters that could vary from road segment to road segment include:

- Number of backbone miles
- Planned construction start date
- Percent of total construction for each construction method to be used.
- Average distance between communications handholes
- Average distance between manholes
- Average distance between cable splice blocks with enclosures
- Segment construction schedule.

4.1.2.2 Device Connection Cost Parameter Summary

Device connection cost parameters include:

- Cross-road (perpendicular to road) and along-road (parallel to the road) distance from the device site to the backbone, if known on a site-by site basis
- Estimated or computed average cross-road and along-road distance from a device site to the backbone, if exact distances are not known on a site-by site basis
- Number of device sites to connect to the backbone
- Preferred construction method (and associated unit costs) or anticipated distribution of construction methods (by percent) for trenching and laying device connection feeder cable
- For fiber optic backbones, the per-unit cost F&I cost of fiber optic converters.

4.1.2.3 Environmental Enclosure Cost Parameter Summary

Environmental enclosure cost parameters include:

- Environmental enclosure F&I unit cost
- Number of environmental enclosures required.

4.2 Leased Circuit Costs

The leased circuit cost element includes one-time charges, fixed recurring charges, and variable recurring usage costs for various types of service. This element applies to the lease and hybrid acquisition options.

A methodology for developing the life-cycle leased circuit costs is presented in Section 4.2.1. Leased circuit cost parameters are summarized in Section 4.2.2.

4.2.1 Leased Circuit Cost Development Methodology

The following seven-step process systematically develops leased circuit cost estimates. The sequence is :

1. Assign leased link identifiers.
2. Assign candidate types of service to each leased link.
3. Solicit cost estimates from service providers.
4. Analyze cost data.*
5. Develop final link configurations.*
6. Derive circuit activation schedules.*
7. Calculate life-cycle leased circuit costs.

* These steps could be performed in parallel.

Assign leased link identifiers - A communications link is described by a unique pair of "from" and "to" locations. These locations can be field device sites, state or local government facilities, facilities of other groups that consume ITS information, and service provider POPs. A given link could be "owned" in some options and leased in others. Some links will be common to many options and others may apply to few options. Communications links for all options and the anticipated loads on these links will be available when link load analysis has been completed.

It is recommended that an alphanumeric identification scheme be devised to logically distinguish leased tail circuits from leased backbone circuits. For example, tail circuit identifiers could begin with a "T" and backbone circuits with a "B." Tabulate the leased links for all options. Review the tabulations and flag the links that are common to two or more options. These links should be assigned the same unique identifier. The remaining links can then be assigned identifiers. It is strongly recommended that a computer database of the link parameters including the unique identifiers be developed and maintained to facilitate computer-aided life cycle cost calculations.

Assign candidate types of service to each link - There are many types of service to be investigated. Examples include:

- Analog POTS
- Dedicated Digital (e.g., 2.4 Kbps, 9.6 Kbps)

- Dedicated Digital Tl
- ISDN

The appropriate type of service for a given link may be a function of multiple factors including:

1. Device type (for circuits connecting devices to the network)
2. Maximum data load on the circuit
3. Polling frequency (for circuits connecting polled devices to the network).

Note that device polling could be a significant cost factor and should not be ignored. For example, selection of a POTS line for a given circuit could yield significantly lower fixed recurring charges when compared to a 2.4 or 9.6-Kbps dedicated digital line. However, when the variable recurring cost for a frequently-polled (e.g., once per minute) device is added, the total POTS cost could be many times greater than the total cost of the dedicated digital service.

Having selected the type of service for each link, quantify the number of lines required to support the maximum load predicted by the link load analysis. Update the link database to include the assignments of type of service and number of lines.

Solicit cost estimates from service providers - In the short term, some useful leased circuit cost data might be gleaned from current actual costs and/or prevailing tariffs. However, for life-cycle costing that extends beyond two or three years in the future, it is strongly recommended that a proactive stance be taken by soliciting and obtaining quotes directly from potential service providers.

A wide cross-section of service providers should be approached with network requirements, a limited number of representative technical architectures, the link definitions and candidate types of service. The intent is to have the providers attempt to optimize the candidate architectures (or propose variations in these architectures) to achieve implementations that they can provide competitively and to provide (possibly proprietary) cost data. The providers should be assured that proprietary cost data will not be disclosed.

Required cost data includes one-time charges (e.g., per-line installation charges), fixed recurring charges (e.g., the monthly charge for dedicated Tl service), and variable recurring charges (e.g., per call or per message charge). It is desired that the pricing estimates will be non-tariffed and applicable for the duration of the communications network life cycle.

Analyze cost data - Ideally, many service providers will supply non-tariffed cost data for each link and type of service pair. The analyst should identify the quotes that give the best "bang for the buck" over the communications network life cycle and store the fixed and recurring cost information in the link database.

If it is not possible to obtain the non-tariffed rates, the tariffed rates can be used as for the initial cost comparisons. Then, as part of the sensitivity analysis discussed in Section 6, the nominal rates can be scaled lower to reflect economies of scale or anticipated price reductions or discounts that would be forthcoming as part of a large-scale or Statewide procurement.

Develop final link configurations - Review the initial assignments of type of service to each leased links. Verify that this is the most cost-efficient service based on analysis of the cost data received from the service providers. Where appropriate, change the type of service designation and required number of lines for that service. Update the link database to include any revisions to type of service and/or number of lines required for that service.

Derive circuit activation schedules - Leased circuit activation schedules will be coupled with the ITS program schedules. Leased tail circuits for existing device sites will be available for activation during the first life cycle year. Leased tail circuits for future device sites will be available for activation as these sites are deployed.

Critical leased backbone circuits (e.g., circuits connecting major facilities) will likely be activated early in the network life cycle. Less-critical circuits will be activated as the need arises.

If firm program circuit activation schedule data is not available, it will be necessary to make scheduling assumptions and to document these assumptions.

The link database should be updated to include a life-cycle activation year for each type of service and number of lines for that link. Year could be specified as absolute (e.g., 1997) or relative to the communications network life cycle (e.g., 1 for the first year of the life cycle, 5 for the fifth year of the life cycle, etc.).

Calculate life-cycle leased circuit costs - The total life-cycle cost of the leased circuit element for a given option is the sum of the one-time, fixed recurring, and variable recurring life-cycle costs of all leased circuits identified for that option.

4.2.2 Summary of Leased Circuit Cost Parameters

The cost parameters common to all communications links include:

- Geographic locations of the connecting end points
- Type of service required
- Number of lines (circuits) per type of service
- Polling frequency (if polled devices are connected by the circuits)
- Circuit activation schedule.

The cost parameters associated with a given type of service include:

- One-time charge incurred per circuit installation
- Fixed monthly recurring charge (applies to distance-insensitive and dedicated distance-sensitive services)
- Variable monthly recurring usage charge, e.g., per call, per message unit (applies to distance-insensitive and distance-sensitive services).

4.3 Communications Equipment Costs

The task of estimating network equipment costs for the network acquisition options may require several iterations depending on the complexity of the options. A methodology for developing the desired equipment costs is presented in Section 4.3.1. The network equipment cost parameters are summarized in Section 4.3.2.

4.3.1 Cost Development Methodology

The following three-step process summarizes the recommended approach to systematically develop network equipment cost estimates. The process encompasses the market survey and system architecture activities necessary to determine a baseline equipment list for each option. The sequence is :

1. Perform a market survey
2. Develop a representative network layout
3. Define sparing strategy
4. Derive schedules
5. Calculate life-cycle network equipment costs

Perform a market survey - Perform a modest amount of market survey (equipment manufacturers and resellers) to identify representative make and model products which could satisfy the technical architectures that have been identified.

Develop a representative network layout - Develop a representative network layout based on the relevant equipment types to determine the appropriate equipment models and quantities needed to match deployment to the locations identified for each architectural option. Create a sample equipment configuration for each distinct model, verify equipment configuration with a vendor representative and obtain purchase cost and lease cost (where applicable) information from a manufacturer or reseller, or through market survey if product is a commodity item

It may be necessary in some cases to derive and cost "custom" equipment configurations that are tailored to meet specific requirements. For example, the vendor might provide the cost of a device with *x* number of ports, and what is needed is the same device withy ports *(y>x)*. The cost of the y-port "model" would be estimated using vendor-supplied per-port costs.

It is strongly recommended that a computer database of network equipment purchase and lease cost parameters be developed and maintained to facilitate computer-aided life-cycle cost calculations.

Define sparing strategy - Spare equipment must be readily available if the network is to be maintained in a timely manner. Alternative sparing strategies include either the purchase of integral spare units or the purchase of components. If integral spare units are purchased, the number of units of each type of equipment to be replaced during the life cycle must be estimated. The total life cycle cost will be the product of the number of units and the unit cost. If components are to be purchased, the life cycle cost can be modeled as an annual recurring cost based on an assumed percentage of the original unit purchase cost.

Derive schedules - Network equipment purchase and lease schedules are linked to the construction and leased circuit acquisition schedules. Hence, equipment purchase and lease schedules should be derived only after the construction and leased circuit schedules have been derived. It may be necessary to make equipment-related scheduling assumptions. If so, these assumptions should be documented.

The network equipment database should be updated to include the life year for purchase or initiation of lease arrangement as appropriate.

Calculate network equipment life cycle costs - The total life-cycle equipment cost for an architectural option is the sum of all equipment purchase, sparing, and lease costs for that option.

4.3.2 Communications Equipment Cost Parameter Summary

Network equipment purchase cost parameters include:

- Equipment unit cost, including warranties
- Number of units to be purchased
- Purchase schedules.

Network equipment lease cost parameters include:

- Equipment unit lease cost
- Number of units to be leased
- Lease schedules.

Network equipment sparing cost parameters include:

- Number of complete spare units to purchase or % of the per-unit equipment purchase cost to be spent on spare components
- Frequency (annually, biannually, etc.) at which new spare units or spare components will be purchased.

4.4 Communications OAM&P Labor Costs

The task of efficiently estimating communications OAM&P labor costs can be complex. Efficient execution of the task will be greatly assisted using the structured methodology presented in Section 4.4.1. The communications OAM&P labor cost parameters are summarized in Section 4.4.2.

4.4.1 Cost Development Methodology

A seven-step process is recommended to systematically develop network OAM&P labor cost estimates. The sequence is :

1. Define a communications operations scenario
2. Define the communications OAM&P functions to be performed
3. Identify the skills required to perform the OAM&P functions
4. Conduct a salary survey
5. Define the required staffing levels (number of full-time equivalent persons) for each skill level
6. Define overhead rates
7. Calculate life cycle network OAM&P labor costs

Define a communications operations scenario - Define how the telecommunications network will be operated and managed. Specify if standards-based equipment will be used. Determine if the network will be managed from one central location.

Define the communications OAM&P functions to be performed - Decompose the communications operations scenario into high-level functions, e.g., fault management, network equipment maintenance. Then decompose the high-level functions into lower-level subfunctions, e.g., maintain help desk, replacement of damaged or failed network equipment.

Identify the skills required to perform the OAM&P functions - Map the OAM&P functions into the skill categories for personnel that will execute these functions. Possible skill categories include but are not limited to network systems engineers, network operators, network equipment technicians, and plant maintenance technicians.

Conduct a salary survey - If any or all of the functions are to be performed in-house, match the in-house skill categories (and associated salaries) with the required OAM&P skills. Industry monitoring entities, such as the Gartner Group, routinely publish salaries (unloaded) for many telecommunications-related skill categories. If any or all of the functions are to be performed by external organizations, review recent survey data and match the published skill categories (and associated salaries) with the required OAM&P skills.

Define the required staffing levels - Given the communications operations scenario, determine which functions, if any, require round-the-clock support (7 days per week, 24 hours per day), extended support (e.g., 7 days per week, 12 hours per day), and on-call (as needed) support. The remaining functions can be performed on a "standard" 40 hours per week schedule. Allocate the required number of full-time equivalents by skill category needed to perform the round-the-clock, extended, and "standard" functions. Estimate the maximum number of hours (annual) by skill category needed to perform any on-call functions.

Define overhead rates - Use any available in-house overhead rate data for those functions (if any) that will be performed in-house. Use any available in-house data for contractor overhead rates for those functions (if any) that are to be performed by external organizations. Otherwise estimate lower and upper bounds of the external overhead rates. Assumed overhead rates can be varied when conducting sensitivity analyses.

Calculate life-cycle communications OAM&P labor costs - For each acquisition option and each life-cycle year, sum the products of the number of full-time equivalents in each applicable labor category, their salaries, and the appropriate overhead rate(s). Add in the labor cost for on-call support by summing the products of the number of annual on-call hours, the equivalent hourly rates for the individuals providing the support, and the appropriate overhead rate(s).

4.4.2 Communications OAM&P Labor Cost Parameter Summary

Communications OAM&P labor cost parameters include:

- Staffing profile (skills required)
- Staffing distributions (number of full-time equivalent persons [in-house and/or external] and annual on-call hours required per skill

category per network architecture option for each calendar, fiscal, or life-cycle year)

- Salaries (unloaded) for all skill categories
- Overhead rates

4.5 Communications Software Costs

The task of efficiently estimating communications software costs can be complex. Efficient execution of the task will be greatly assisted using the structured methodology presented in Section 4.5.1. The communications software cost parameters are summarized in Section 4.5.2.

4.5.1 Cost Development Methodology

A ten-step process is recommended for systematically developing network software cost estimates. The sequence is:

1. Analyze all communications software requirements.
2. Allocate communications software requirements to ITS components.
3. Estimate the number of licenses needed for the candidate COTS products.
4. Contact vendors and resellers.*
5. Identify non-COTS products to be enhanced.
6. Estimate the number of lines of new code.*
7. Select productivity rates for enhancing existing software and developing new software.
8. Derive a composite labor rate.
9. Derive network software schedules.
10. Calculate the life-cycle communications software costs

* The COTS and non-COTS steps can be executed in parallel.

Analyze all communications software requirements - The baseline communications software requirements should be thoroughly reviewed and analyzed to fully understand the network functions to be performed.

Allocate communications software requirements to ITS components - The communications software functions should be mapped to any candidate COTS software products. If no COTS candidate is identified, then the function will be performed by either an existing non-COTS product or by a new software product that must be designed and developed.

Estimate the number of licenses needed for the candidate COTS products - Given the operations scenario, including the distribution of communications functions, the number of licenses that are required for each candidate COTS product can be estimated for each network architecture option.

Contact vendors and resellers - Vendors and resellers should be contacted to obtain current purchase and annual maintenance costs for the candidate COTS products.

Identify non-COTS products to be enhanced - Enhancements to existing non-COTS products may be needed to add required functionality. The number of lines of enhanced code must be estimated.

Estimate the number of lines of new code - The number of lines of code to be designed and developed for each identified new non-COTS product must be estimated.

Select productivity rates - Productivity rates (staff hours per delivered source instruction [DSI]) for enhancing existing software and developing new software must be selected. If the software enhancement and development is to be performed in-house, use available data from past projects. Otherwise, industry monitoring entities, such as the Gartner Group, could supply ranges of productivity rates.

Derive a composite labor rate - The cost of labor to enhance and develop communications software could be significant. Typically, software projects involve the talents of managers, designers, developers, and testers. A composite labor rate for the above mix of skills is appropriate for a first-cut estimate of labor costs. If the software enhancement and development is to be performed in-house, available data from past projects can be used to derive a composite hourly rate. Otherwise, industry monitoring entities such as the Gartner Group could supply composite rate data.

Derive network software schedules - Network software schedules will be derived from the ITS program schedules. The ITS program schedules will dictate when and where software functional capabilities are needed. Using this information, COTS software procurement schedules can be defined. Network software enhancement and development start schedules can be estimated by working backwards from the latest allowable availability date for that software.

Calculate the life-cycle communications software costs - The COTS procurement and annual maintenance costs can be calculated given the specific COTS products and number licenses to be procured, the procurement and annual maintenance costs per license, and procurement schedules. The total cost of enhanced existing code and the total cost to develop new code can be calculated given the estimated lines of code involved, the software productivity rate, and the composite staff labor rate. This total cost can be distributed across life cycle years using the start and end dates derived in the previous step.

4.5.2 Communications Software Cost Parameter Summary

Communications software cost parameters include:

- List of required COTS software products and number of licenses for each product
- COTS software product purchase and annual maintenance costs
- List of existing software programs to be enhanced and the estimated lines of enhanced code
- List of software programs to be developed and the estimated lines of developed code for each program

- Software productivity rate (staff hours per DSI)
- Composite staff labor rate
- Software procurement schedules
- Software enhancement/development schedules

Section 5 - Calculate and Compare Option Life-Cycle Costs

This section discusses the process of calculating the life-cycle costs of the acquisition options and provides examples of how the life-cycle costs of the different options can be presented for effective comparison.

5.1 Calculate Life-Cycle Costs

Section 4 describes five ITS communications cost elements and identifies the key parameters that drive the costs. This section introduces the concept of present value analysis and discusses how it relates to cost tradeoff analysis. It also offers guidance on how to automate the process of calculating the total life-cycle costs for all options.

5.1.1 Present Value Analysis

The costs of each acquisition option will be incurred throughout the life cycle. Present value analysis converts all costs to their current (i.e., present) value. It assumes that a dollar received or spent today is worth more than a dollar received or spent tomorrow. A dollar invested today begins to earn interest immediately. A dollar invested in the future cannot earn interest until it is invested. The difference in present value cost is the interest earned by the dollar today before a future dollar is invested. When analyzing life-cycle costs for periods of more than three years, the OMB recommends that costs be expressed in terms of present value.

The baseline year (i.e., the first life-cycle year) establishes the time reference point for present value analysis. The costs in future years are then calculated as if they occurred in the baseline year by using discount factors.

Discount factors are calculated using the formula:

$$\text{factor} = 1/(1+i)^{t},$$

where i is the appropriate discount rate and t is the life-cycle year.

When performing cost tradeoff analysis and lease-buy analysis, the cost of funds is a key concern. The OMB provides guidance on the discount rates to be used for these types of analyses. These rates are discussed in Sections 5.1.1.1 and 5.1.1.2, respectively.

For a given life-cycle year, different factors apply for different assumptions of when the costs will be incurred within the year. Typically, costs are assumed to occur at either the beginning of the year, in the middle of the year, or at the end of the year. Many costs (e.g., construction, leased circuits, leased equipment, labor) are spread evenly throughout the year. Some major costs such as capital equipment tend to occur at the beginning or middle of a fiscal year.

Generally speaking, mid-year factors should be used unless the timing of the costs cannot be specified or if they are known to occur at the end of the year. If the latter is true, then end-of-year factors should be used.

5.1.1.1 Cost Tradeoff Analysis

Cost tradeoff analysis compares real (constant purchasing power) dollars. To make meaningful comparisons, constant-dollar cost flows must be discounted using real Treasury borrowing rates for marketable securities of comparable maturity to the period of analysis. Table 5-1 summarizes the current OMB real interest rates on treasury notes and bonds of various maturities. Referring to the table, the average real rate is currently significantly below 7 percent. For analysis of ITS programs with durations other than those cited in the table, linear interpolation can be used. For example, a six-year project can be evaluated with a rate equal to the average of the 5-year and 7-year rates. For program durations exceeding 30 years, the 30-year interest rate may be used.

Table 5-1. Real Interest Rates on Treasury Notes and Bonds

	Treasury Note and Bond Maturity (Years)				
	3	5	7	10	30
Interest Rate (%)	2.7	2.7	2.8	2.8	3.0

Table 5-2 presents the discount factors for the first ten years of an ITS network lifetime. These factors have been calculated assuming a 2.8% discount rate, which is the average of the 7-year and 10-year rates shown in Table 5-1. As noted above, the mid-year factors should be used if it is assumed that the costs occur evenly throughout the year. If the timing of the costs is uncertain or if it is assumed that the costs occur at the end of the year, the end-of-year factors should be used.

Table 5-2. !0-Year Discount Factors for 2.8% Real Discount Rate

	Discount Factors		
Life-Cycle Year	Beginning of Year	Middle of Year	End of Year
1	0.97276	0.98629	1.00000
2	0.94627	0.95942	0.97276
3	0.92049	0.93329	0.94627
4	0.89542	0.90787	0.92049
5	0.87103	0.88314	0.89542
6	0.84731	0.85909	0.87103
7	0.82423	0.83569	0.84731
8	0.80178	0.81293	0.82423
9	0.77994	0.79079	0.80178

	Discount Factors		
Life-Cycle Year	**Beginning of Year**	**Middle of Year**	**End of Year**
10	0.75870	0.76925	0.77994

5.1.1.2 Lease-Purchase Analysis

Some states may wish to explore the option of leasing versus buying ITS communications equipment. Equipment lease-purchase cost analysis compares nominal dollars that are not adjusted to remove the effects of inflation. Nominal cost flows must be discounted using nominal Treasury borrowing rates for marketable securities of comparable maturity to the period of analysis. Table 5-3 summarizes the current OMB nominal interest rates on treasury notes and bonds of various maturities. Referring to the table, the average real rate is currently below 7 percent. For analysis of ITS programs with durations other than those cited in the table, linear interpolation can be used. For example, a six-year project can be evaluated with a rate equal to the average of the 5-year and 7-year rates. For program durations exceeding 30 years, the 30-year interest rate may be used.

Table 5-3 Nominal lnferesf Rates on Treasury Nofes and Bonds

	Treasury Note and Bond Maturity (Years..)				
	3	**5**	**7**	**10**	30
Interest Rate (%)	5.4	5.5	5.5	5.6	5.7

Table 5-4 presents discount factors for the first ten years of an ITS network lifetime. These factors have been calculated assuming a 5.55% discount rate, which is the average of the 7-year and lo-year rates shown in Table 5-3. As noted above, the mid-year factors should be used if it is assumed that the costs occur evenly throughout the year. If the timing of the costs is uncertain or if it is assumed that the costs occur at the end of the year, the end-of-year factors should be used.

Table 5-4. 10-Year Discount Factors for 5.55% Nominal Discount Rate

	Discount Factors		
Life Cycle Year	**Beginning of Year**	**Middle of Year**	**End of Year**
1	**0.94742**	**0.97335**	**1 .00000**
2	**0.89760**	0.92217	0.94742
3	0.85040	0.87368	0.89760
4	0.80569	0.82774	0.85040
5	0.76332	0.78422	0.80569
6	0.72319	0.74298	0.76332
7	0.68516	0.70392	0.72319
8	0.64913	0.66690	0.68516
9	0.61500	0.63184	0.64913
10	0.58266	0.59861	0.61500

5.1.2 Automate Calculations

Unless few architecture options are identified, it may be necessary to perform a large number of calculations. Regardless of the approach selected to calculate costs, the following functional capability is needed for all options:

- Vary input parameters
- Distribute costs over life-cycle years
- Rollup annual component costs of individual cost elements
- Rollup annual costs of all cost elements
- Convert dollars to present value dollars
- Calculate cumulative total life-cycle costs
- Calculate cumulative costs for subsets of the total life cycle, e.g., first five years, first ten years, etc.

Given the potential need to gather, store, manage, and manipulate a large volume of data, consideration should be given to automate the cost calculation and reporting process. There are many computer-based commercial tools to choose from, including spreadsheet applications and database management systems. The choice of the specific tool is not as important as planning how the tool will be used.

The following suggestions are offered to assist in the planning process:

- Implement a table-driven system
- Implement a computation hierarchy
- Separate cost calculation functions and reporting functions

By storing the values of key parameters in tables and referencing the tables in equations, any parameter updates will automatically "ripple" through the system and into the results.

By devising a top-down/bottom-up computational hierarchy for each cost element, error traceability will increase while debugging time is reduced, and it will be possible to generate reports with increasing levels of detail. Figure 5-1 depicts one possible hierarchy, featuring the leased circuit cost element lower-level details. Referring to the figure, a total of four levels of hierarchy are depicted including:

- Option level
- Cost element level
- Circuit level
- Link level

The lowest level of cost for the leased circuit cost element is the *link* level. For each option, the one-time and monthly recurring costs for each leased link and type of service defined for that option are stored in a data table or database.

The link cost data is input to *the circuit* level where it is combined with other data such as the number of lines per link and the year the circuit(s) will be activated. The result is the individual life-cycle costs for each leased circuit.

The per-circuit life-cycle costs are input to the *cost element* level, and rolled up to yield the leased circuit cost element life-cycle cost for each option.

The life-cycle costs for all cost elements, including the leased circuit cost element, are rolled up at the option level to define the total life-cycle cost of each option.

Finally, by identifying the interface between the cost calculation and report generation functions (e.g., a common data format) early on in the planning process, both functions can be developed and tested in parallel. This approach will also facilitate the future enhancement of either the cost calculation function, or cost reporting function, or both.

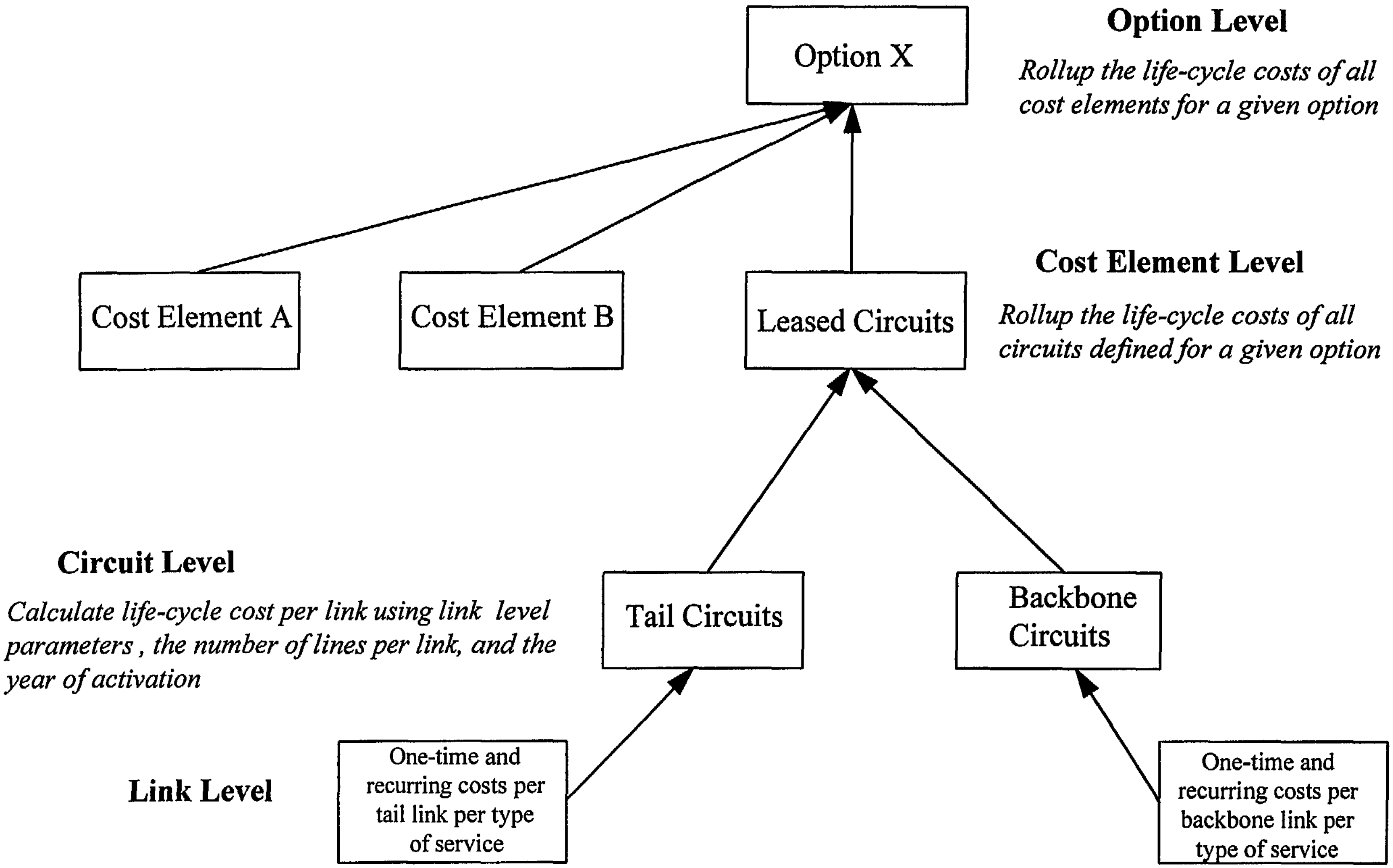


Figure 5-1. Sample Cost Computation Hierarchy

5.2 Compare Life-Cycle Costs

This section provides examples of the type of reports that can be generated to facilitate the presentation of life-cycle costs for individual options, and the comparison of the life-cycle costs of two or more options.

The following sections present and discuss the following generic reports:

- Life-cycle cost summary for all options
- Annual life-cycle costs for option groups
- Lowest cost option details
- Lease, build, and hybrid break-even analysis

52.1 Life-Cycle Cost Summary: All Options

Table 5-5 presents a sample results summary for a multi-year life-cycle cost analysis study that includes build, lease, and hybrid acquisition options. costs are expressed in both current and discounted dollars for comparison. The options have been assigned identifiers in accordance with the scheme suggested in Section 3.2.5. Referring to the table, there are two lease options (the option identifiers have a leading "L"), three hybrid options (the option identifiers have a leading "H"), and one build option (the option identifier has a leading "B").

The lease options include two nominal technical architectures (Ll and L2). The hybrid options include one nominal technical architecture (Hl) and two variations (H1_1,H1_2). One build option (B1) is defined.

Table 5-5. Life-Cycle Cost Summary for All Options

	Ten Years		Five Years	
Option	current $	discounted $	current $	discounted $
L 1	$	$	$	$
L 2	$	$	$	$
H 1	$	$	$	$
H 1 _ 1	$	$	$	$
H 1 _ 2	$	$	$	$
B 1	$	$	$	$

5.2.2 Annual Life-Cycle Cost for Option Groups

Table 5-6 presents a sample format for presenting detailed annual cost breakouts for the three hybrid acquisition options. Referring to the table, the costs of all five cost elements are shown for both the first five years and ten years of the life cycle. Percentages of the total option cost are also calculated for the five cost elements for the five- and ten-year periods.

Table 5-6. Annual Life-Cycle Costs for the Hybrid Acquisition Options

					Life Cycle Year							Ten Year		Five Year	
Option	Cost Category	1	2	3	4	5	6	7	8	9	10	Subtotal	% Total	Subtotal	% Total
H1	construction	$	$	$	$	$	$	$	$	$	$	$	%	$	%
	equipment	$	$	$	$	$	$	$	$	$	$	$	%	$	%
	leased circuits	$	$	$	$	$	$	$	$	$	$	$	%	$	%
	OAM&P Labor	$	$	$	$	$	$	$	$	$	$	$	%	$	%
	network software	$	$	$	$	$	$	$	$	$	$	$	%	$	%
	Totals	$	$	$	$	$	$	$	$	$	$	$	%	$	%
H1_1	construction	$	$	$	$	$	$	$	$	$	$	$	%	$	%
	equipment	$	$	$	$	$	$	$	$	$	$	$	%	$	%
	leased circuits	$	$	$	$	$	$	$	$	$	$	$	%	$	%
	OAM&P Labor	$	$	$	$	$	$	$	$	$	$	$	%	$	%
	network software	$	$	$	$	$	$	$	$	$	$	$	%	$	%
	Totals	$	$	$	$	$	$	$	$	$	$	$	%	$	%
H1_2	construction	$	$	$	$	$	$	$	$	$	$	$	%	$	%
	equipment	$	$	$	$	$	$	$	$	$	$	$	%	$	%
	leased circuits	$	$	$	$	$	$	$	$	$	$	$	%	$	%
	OAM&P Labor	$	$	$	$	$	$	$	$	$	$	$	%	$	%
	network software	$	$	$	$	$	$	$	$	$	$	$	%	$	%
	Totals	$	$	$	$	$	$	$	$	$	$	$	%	$	%

5.2.3 Lowest Cost Option Details

Figures 5-2 and 5-3 present two different views of a lowest cost option.

Figure 5-2 is a stacked bar chart profile of the annual costs. The contributions of the five cost elements are stacked together in one bar for each life-cycle year. The relative proportions of cost allocated to each cost element can be inferred from visual inspection, and the total annual cost can be read directly from the scale on the left side of the graph.

Figure 5-3 is a pie chart depicting the percentages of the total life-cycle cost assigned to each of the five cost elements. The relative proportions of cost allocated to each cost element can be inferred from visual inspection, and the actual percentages are also shown next to each pie "slice."

These and other views could be used to convey the results of cost tradeoff studies.

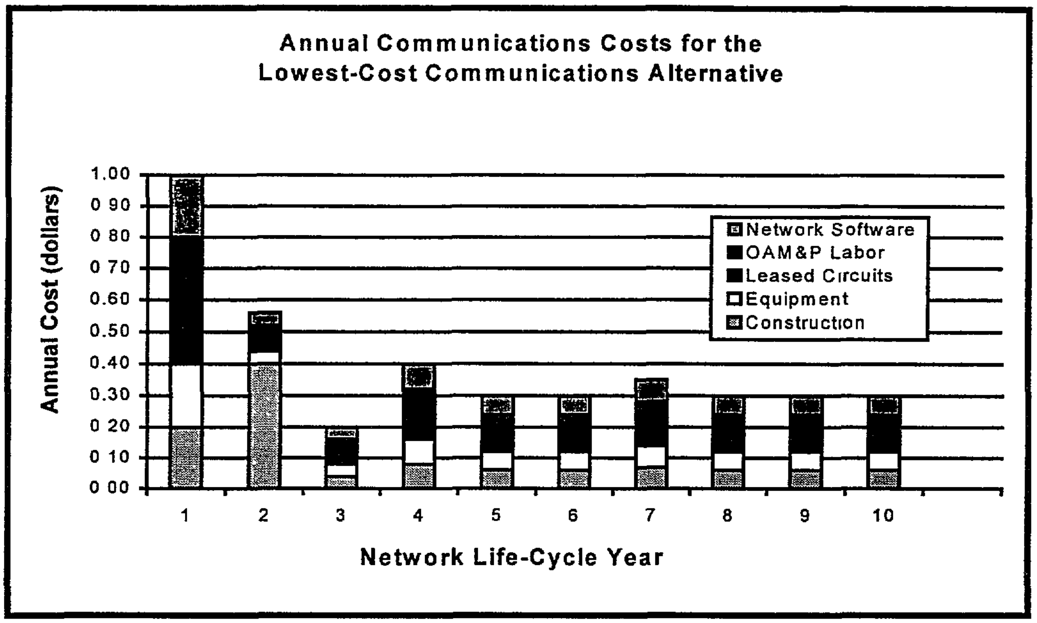


Figure 5-2. Annual Communications Costs for the Lowest Cost Alternative

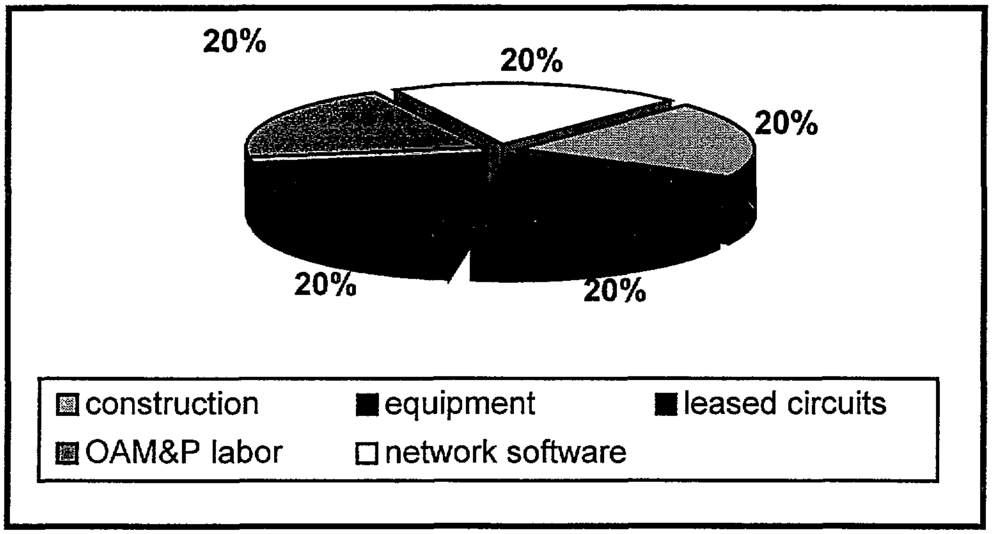


Figure 5-3. Lowest Cost Alternative by Component

5.2.4 Lease, Build, and Hybrid Break-Even Analysis

The point in the telecommunications life cycle where the costs of two different options converge is known as the break-even point. The associated elapsed time from the beginning of the life cycle is called the payback period. The number of life cycle years to be analyzed should be sufficiently large to determine if a break-even point exists for lease versus buy, but not too large to invalidate key assumptions regarding costs trends and the availability of technology.

Figure 5-4 is a line graph of the cumulative costs, by life-cycle year, for the hypothetical lowest cost lease, build, and hybrid options. Referring to the figure, the cumulative cost of the lease option is initially lower than that of the hybrid option. However, there is a break-even point during life-cycle Year 4, and from then on, the cumulative cost of lease exceeds that of the hybrid.

There is no break-even point for the build option within the first ten years of the life cycle.

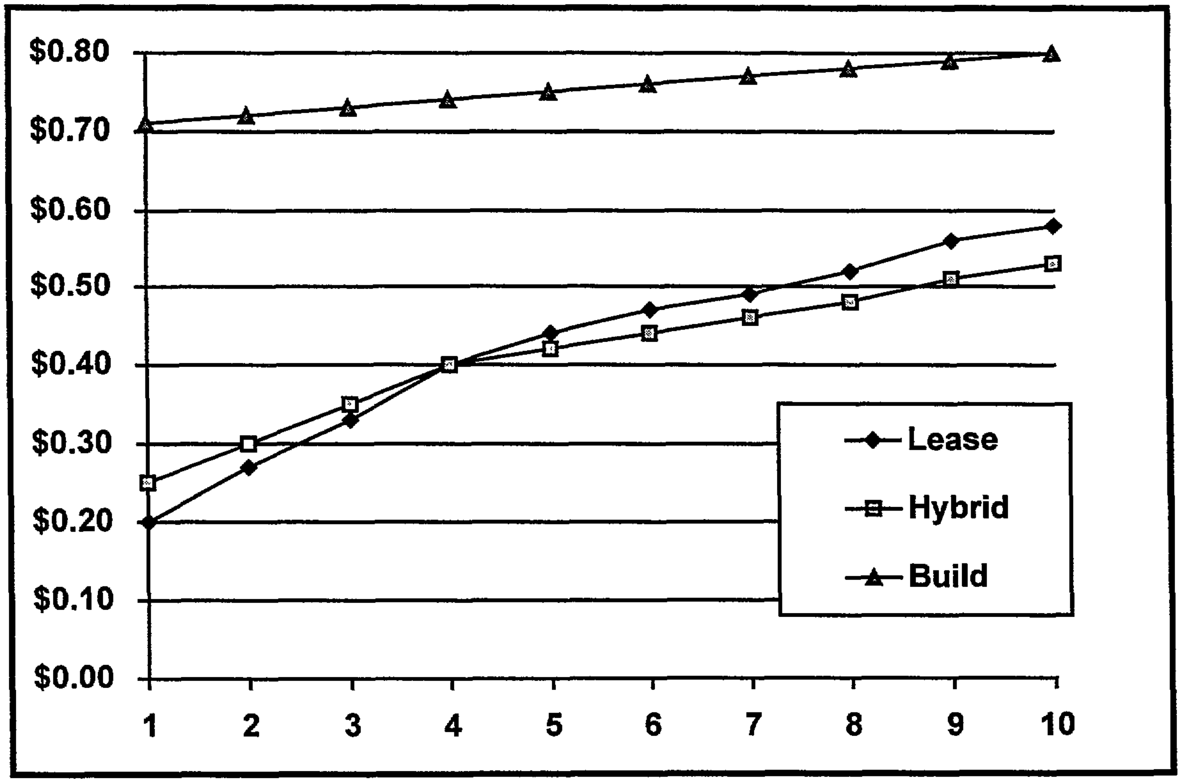


Figure 5-4. Lease, Build, and Hybrid Break-Even Analysis Graph

Section 6 - Perform Sensitivity Analysis

If there are uncertainties in the initial cost tradeoff analysis, it would be helpful to know if reasonable changes in assumptions, topologies, technical architectures, and/or cost parameter values could significantly change the rankings of the options. Sensitivity analysis is the process of quantifying the effect of changes in communications models and/or cost input parameters on the rankings.

Features that facilitate the performance of sensitivity analysis can be planned and incorporated into the cost models prior to the start of a cost tradeoff study. However, sensitivity analysis need not actually be conducted if the initial rankings show that one option is clearly superior to all others.

To summarize, sensitivity analysis can be performed by varying parameters in existing cost models, by identifying additional options through analysis and costing these additional options, or both. Section 6.1 discusses variation of parameters. Section 6.2 addresses identification and costing of new options.

6.1 Vary Cost Parameters

As a rule, sensitivity analysis should address the key input parameters for the most significant cost drivers. They are the most likely parameters to alter the initial cost rankings.

The key parameters should be identified and ranked in order of relative importance prior to implementing the computational models described in Section 5. Having done this, care should be taken to assure that the key parameters can be easily modified by updating data tables and/or scaling default data values within the cost models. For example, equations that contain key cost parameters to be scaled, could include an explicit scaling factor for that parameter which can be easily varied by updating data tables.

A two- or three-level scale (high-low, or high-medium-low) can be used to rank the likely impact of individual cost parameters on total cost. Cost parameter rankings are presented in Section 6.1.1. Section 6.1.2 offers suggestions for conducting sensitivity analysis by variation of cost parameters.

6.1 .1 Cost Elements, Parameters, and Rankings

Table 6-l lists the cost elements, a subset of the parameters driving the cost of these elements, and subjective rankings of the impact of each parameter. The parameter list was compiled for the purpose of illustration and hence is not complete. In an actual cost tradeoff study, all cost parameters should be analyzed and ranked.

Table 6-1. Cost Element Parameter Impact Rankings

Cost Element	Cost Parameter	Impact
Construction	unit costs for applicable construction methods	High
	the estimated percentages of the total construction for each construction method	High
	average cross-road trenching distance for devices located on the same side of the road as the backbone	High
	average cross-road trenching distance for devices located on the same side of the road as the backbone	High
	distribution of along-road distance from device sites to the nearest network POP	High
	communications handhole furnish and install unit cost	Low
	fiber optic converter unit cost	Low
Leased Circuits	device polling frequency	High
	long term rate structures	High
Equipment	purchase cost	High
	sparing rates	High
	long term lease rates	Medium
OAM&P	salaries	High
	overhead rates	High
	staffing level	Medium
Communications Software	lines of code for enhanced and developed communications software	High
	software productivity rates	High
	software development labor rates	High
	commercial off-the-shelf (COTS) software purchase costs	Low

6.1.2 Sensitivity Analysis Techniques

The analyst will thoroughly review the initial cost tradeoff study results to identify the cost element or elements that contribute the largest shares of the total life-cycle cost for each option. Having done this, tools such as a parameter impact rankings table will assist in selecting the cost parameters to vary.

The analyst then has the option of performing sensitivity analysis by varying one parameter at a time per option or by varying two or more parameters simultaneously. Simultaneous multiple parameter variations will be useful in promptly determining if the highest-ranked option can retain that ranking in spite of worst case cost growth assumptions.

For example, assume that the lowest cost option is lease and the second lowest cost option is hybrid. The nominal values of selected lease cost parameters would be scaled as shown in Table 6-2 to reflect cost growth.

Table 6-2. Lease Option Pessimistic Sensitivity Analysis

Cost Element	Cost Parameter	Scaled Cost
Construction	unit costs for applicable construction methods	> nominal
	average cross-road trenching distance for devices located on the same side of the road as the backbone	> nominal
	average cross-road trenching distance for devices located on the side of the road opposite to the backbone	> nominal
Leased Circuits	device polling frequency	> nominal
	long term rate structures	> nominal
Equipment	purchase cost	> nominal
	long term lease rates	> nominal

Note: > means greater than.

On the other hand, the values of selected hybrid cost parameters shown in Table 6-3 would be scaled to reduce the nominal costs. If lease with cost growth remains the lowest cost option compared to hybrid with cost reduction, no further analysis is needed. Otherwise, further analysis will be required to resolve obvious inconsistencies. For example:

- unit construction method costs cannot be simultaneously higher and lower than nominal

- average distances cannot be simultaneously higher and lower than nominal
- device polling frequencies cannot be simultaneously higher and lower than nominal
- long term leased circuit rate projections cannot be simultaneously higher and lower than nominal
- equipment purchase costs cannot be simultaneously higher and lower than nominal
- long term equipment lease rate projections cannot be simultaneously higher and lower than nominal.

Table 6-3. Hybrid Option Optimistic Sensitivity Analysis

Cost Element	**Cost Parameter**	**Scaled Cost**
Construction	unit costs for applicable construction methods	< nominal
	average cross-road trenching distance for devices located on the backbone side of the road	< nominal
	average cross-road trenching distance for devices located on the side of the road opposite to the backbone	< nominal
Leased Circuits	device polling frequency	< nominal
	long term rate structures	< nominal
Equipment	purchase cost	< nominal
	long term lease rates	< nominal

Note: <means less than.

6.2 Identify and Cost New Options

While reviewing the initial cost tradeoff results, the analyst may identify ways of reducing the cost of one or more options, thus making them more competitive with the lowest cost option. For example, upon review of the leased circuit costs for some lease and/or hybrid class options, it may be possible to use a different type of service for some circuits and still satisfy all communications requirements while at the same time reducing total life-cycle costs.

For the above example, the analyst would have the choice of either redefining existing options or introducing new options. Either way, these options would be costed and compared to their peers.

Acromym List

ATM	Asynchronous Transfer Mode
ATR	automated traffic recorder
BISDN	Broadband Integrated Services Digital Network
CCTV	closed circuit television
CHART	Chesapeake Highway Advisories (for) Routing Traffic
CMS	changeable message sign
CODECS	coders/decoders
COTS	commercial off-the-shelf
C S C	Computer Sciences Corporation
DCS	digital cross-connect system
DDS	Dedicated Digital Services
DSI	delivered source instruction
F&I	furnish and install
FDDI	Fiber Distributed Data Interface
FDM	frequency-division multiplexing
FHWA	Federal Highway Administration
GIS	Geographic Information System
HAR	Highway Advisory Radio
HDTV	high definition television
IS/IT	information systems/information technology
ISDN	integrated services digital network
ITS	Intelligent Transportation System
ITU	International Telecommunication Union
JPEG	Joint Photographic Experts Group
JPO	Joint Program Office
Kbps	kilobits per second
LAN	local area network
Mbps	megabits per second

MDOT	Maryland Department of Transportation
MHz	megahertz
M-JPEG	Motion Joint Photographic Experts Group
MPEG	Motion Pictures Experts Group
MSHA	Maryland State Highway Administration
MSP	Maryland State Police
MTBF	mean time between failure
MTTR	mean time to repair
NTSC	National Television Standards Committee
OAM&P	operations, administration, maintenance and provisioning
OMB	Office of Management and Budget
OTD	overhead traffic detector
P/T/Z	pan, tilt, zoom
PBFI	PB Farradyne Inc.
POP	point-of-presence
POTS	plain old telephone service
RMA	reliability, maintainability, availibility
RWIS	Road & Weather Information System
SDH	Synchronous Digital Hierarchy
SHA	State Highway Administration
SMDS	Switched Multimegabit Data Service
SOC	Statewide Operations Center
SONET	Synchronous Optical NETwork
SSR	spread sprectrum radio
TAR	travelers advisory radio
TDM	time-divsion multiplexing
TOC	Traffic Operations Center
US DOT	United States Department of Transportation
VMS	variable message sign