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Guidelines for Successful Traffic Control Systems

Volume II: Final Report

Research, Development, and Technology
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FOREWORD

This report is the second of a two-volume series resulting from the study, "Investigation of Successful Traffic Control System Design, Installation and Operations Practices." The report will be of interest to designers and operators of traffic control systems or those interested in possibly implementing a traffic control system.

In recent years, traffic control systems have become increasingly popular as a means of combating urban traffic congestion problems. However, many systems have experienced implementation problems ranging from cost overruns during construction to excessive hardware and software malfunctions during system operation. The objectives of this study were to prepare guidelines for the successful implementation of traffic control systems and to critically assess the performance of new and emerging communications technologies in traffic control system applications.

This second volume provides a detailed discussion of the guidelines developed for the successful implementation of traffic control systems. The first volume is an executive overview of this portion of the study. Another two-volume report series resulting from this study (FHWA-RD-88-011 and 012) covers the communications technology assessment portion of the study.

The research reported herein is part of Nationally Coordinated Program (NCP), Program Area B.1, "Traffic Management Systems."

Copies of this report are being distributed to selected FHWA Headquarters elements and field offices, and to selected transportation officials. Additional copies of this report for the public are available from the National Technical Information Service (NTIS), Department of Commerce, 5285 Port Royal Road, Springfield, Virginia 22161. A charge will be imposed for each copy ordered from NTIS.

R J Betsold

R. J. Betsold, Director
Office of Safety and Traffic
Operations R&D

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16. Abstract

A traffic control system is generally considered successful if it meets the needs of the agency and the motorist, if it has been implemented within a reasonable time and budget, if it functions properly, and if it is utilized to its full potential over a number of years. This report presents guidelines for the planning, design, installation, operation, and maintenance of successful systems. Numerous examples are also included in the report, along with the bibliography of basic technical references in the area of traffic control systems.

The focus of the guidelines is the system process -- the procedures and practices by which system success may be achieved. The guidelines do address system hardware and software, but with a procedural and management orientation.

The guidelines are structured to follow the logical process of a systems life from initial planning to continuing operations and maintenance, and overall management. An executive summary of the guidelines is available in Volume I, publication no. FHWA-RD-88-013.

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METRIC (SI*) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

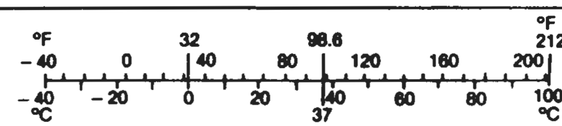
Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	2.54	millimetres	mm
ft	feet	0.3048	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km
		AREA		
in^2	square inches	645.2	millimetres squared	mm^2
ft^2	square feet	0.0929	metres squared	m^2
yd^2	square yards	0.836	metres squared	m^2
mi^2	square miles	2.59	kilometres squared	km^2
ac	acres	0.395	hectares	ha
		MASS (weight)		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
		VOLUME		
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft^3	cubic feet	0.0328	metres cubed	m^3
yd^3	cubic yards	0.0765	metres cubed	m^3

NOTE: Volumes greater than 1000 L shall be shown in m^3.

Symbol	When You Know	Multiply By	To Find	Symbol
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi
		AREA		
mm^2	millimetres squared	0.0016	square inches	in^2
m^2	metres squared	10.764	square feet	ft^2
km^2	kilometres squared	0.39	square miles	mi^2
ha	hectores (10 000 m^2)	2.53	acres	ac
		MASS (weight)		
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1 000 kg)	1.103	short tons	T
		VOLUME		
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m^3	metres cubed	35.315	cubic feet	ft^3
m^3	metres cubed	1.308	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



These factors conform to the requirement of FHWA Order 5190.1A.

* SI is the symbol for the International System of Measurements

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1. INTRODUCTION

This report has been prepared for the study entitled "Investigation of Successful Communications and Traffic Control System Design, Installation, and Operations Practices". The project objectives were to:

- Develop through investigation of in-depth case studies, guidelines for the design, procurement, installation, and operation of successful traffic control systems.
- Assess the performance of existing and new or emerging communications technologies for use in traffic control systems.

This report focuses on the first objective -- guidelines for successful systems. Information on communication technologies and their application in traffic control systems is provided in a separate report.

BACKGROUND

A traffic control system is defined in the Federal-Aid Highway Program Manual as "an array of human, institutional, hardware and software components, designed to monitor and control traffic, and to manage transportation on streets and highways and thereby improve transportation performance, safety, and fuel efficiency."(4) The vast majority of traffic signal systems and freeway surveillance and control systems have successfully achieved the above-stated goals, providing a cost-effective means for reducing urban congestion. An undue number of systems, however, have experienced various degrees of difficulty. These "failures" have included significant delays and cost overruns during system implementation, an excessive number of hardware and software malfunctions following system acceptance, control strategies (e.g., timing plans) that have not been kept up-to-date, lack of properly trained operations and maintenance personnel, the inability to expand the system or enhance its functional capabilities in the future, or some combination. Whatever the problem, the potential benefits of system control have not always been fully realized and, in some situations, the traffic engineering agency has lost credibility with the public as well as within the governmental structure.

This past experience with traffic control systems leads to some very important questions. Why have some systems been successful while others have not? Are there key factors that weave a common thread through system successes which should be followed? Similarly, are there certain attributes common to system failures which should be avoided? The orientation of this project was to provide answers to these and related questions. The results of the investigation have been documented in the form of guidelines so that future traffic control systems can be successfully designed, installed, operated, and maintained.

PROJECT OVERVIEW

All four of the system components listed in the previous system definition -- human, institutional, hardware, and software -- can impact the success (or failure) of a traffic control system. This research effort concentrated on the human and institutional elements. The focus of the guidelines is the **system process** -- the procedures and practices by which system success may be achieved. It is noted that the guidelines do address hardware and software components, but with a procedural and management orientation. Additionally, a bibliography of basic technical references in the area of traffic control systems is provided in the appendix.

The guidelines for successful systems were based on information from the following sources:

- Review of applicable literature.
- In-depth case study evaluations. Nine traffic control systems, representing a wide range of system technologies and processes, were visited and investigated with respect to their successes and failures. The purpose of these case studies was to obtain generic information on the system process which is applicable to all traffic control systems. The information was obtained from a review of system reports, plans and specifications, project files, and other system documentation; observations of system operation and maintenance activities; and interviews with persons involved in the system process, including traffic engineers, system managers, designers, contractors, inspectors, operators and maintainers, administrators, FHWA representatives, and other government officials (e.g., police).
- Experiences of the project team, with knowledge and input from FHWA representatives.

The guidelines are applicable to all types and sizes of computer-based traffic control systems. They are directed primarily towards government agencies that are planning to initiate a system project of some kind (new, expansion of existing, retrofit), system designers and consultants, and those responsible for construction management and system operations and maintenance. It is believed, however, that other participants of the system process, such as contractors, transportation managers, and government agencies with a review function, may also benefit from the information contained in the guidelines.

REPORT ORGANIZATION

The report is organized into six chapters including this introductory chapter. The next chapter provides an overview of management considerations which can greatly impact the system process and a system's success. The remaining chapters follow the logical process of a system's life as follows:

3. SYSTEM PLANNING
4. SYSTEM DESIGN
5. SYSTEM IMPLEMENTATION
6. SYSTEM OPERATION AND MAINTENANCE

The system phases listed above are interrelated. The quality and completeness of work in a preceding phase has a direct and significant impact on the success of subsequent phases. Furthermore, most system components (both technical and procedural ones) need to be addressed and/or analyzed in some manner during several, if not all, of the phases of a system's life. For example, adequate construction management must be anticipated during the planning phase, the project engineer and inspection personnel need to be designated and possibly trained prior to the start of system construction, and these efforts must then be reflected during system implementation. Similarly, training and documentation need to be specified during the system design phase, and then provided as part of system implementation activities if the system is to be successfully operated and maintained.

This overlapping and interdependence of system phases does create some difficulties in terms of organizing the report. In general, a particular aspect of the system process is discussed in the chapter representing the system phase in which it has the most significance and impact. The component may also be mentioned in other chapters as appropriate. To make cross-referencing easier, an index of key terms and procedural elements has been provided.

2. MANAGEMENT OVERVIEW

In every process there is an underlying structure which shapes and controls events. This framework consists of formal elements (e.g., contract documents and agreements, Operations Plan, written procedures), as well as informal elements (e.g., human relationships, cooperation and commitment of participants). Experience has shown that, far beyond any formal written controls, system success ultimately depends on the informal elements. A successful system must therefore be a human success if it is ever to be a technological one; and this requires that the system process be properly managed.

This brief chapter discusses system success, and summarizes some of the human considerations and management practices which are so essential to system success. The management overview is applicable to all aspects and phases of the system process.

SYSTEM SUCCESS

What exactly is a successful traffic control system? In developing a definition of system success it is important to remember that there are two distinct periods of a system's life:

- Time preceding its start-up and initial operation, during which the planning, design, implementation phases occur.
- Period following system start-up when the user is responsible for operating and maintaining the system.

The latter period -- the time when the traffic flow improvements are actually realized -- is the more important of the two. During this poststart-up period, it is crucial that the system be properly operated and maintained, and that control strategies be updated on a continuing basis. However, as previously noted, the success of one system phase is dependent upon the events during the previous phases. Thus, during the prestart-up period, it is important that the optimum traffic control system be selected and that this system be designed, installed, and integrated to provide the necessary features and functions.

It is possible to have an absolutely dismal prestart-up period -- one that is wrought with extensive delays, significant cost overruns, and even litigation -- and still end up with a successful system in terms of improved traffic flow and proper operation. However, any time "wasted" during the system design and construction phases will delay the accrual of system benefits to the motoring public. The additional funds required to cover any cost overruns could have been used to expand the system, or for some other worthwhile public works expenditure. Furthermore, problems experienced during system implementation, particularly if they are reported by the media (and they usually are), may undermine the credibility of the transportation agency within the governmental hierarchy and in the eyes of the motorists. Thus, any definition of system success must also include that the system is designed and implemented within a reasonable time and budget.

A traffic control system is generally considered "successful" if it has been designed to meet the needs of the agency and motorist; if the system has been implemented within a reasonable time and budget; if the various hardware and software components have been installed, integrated, operated, and maintained to function properly; <u>and</u> if the system is utilized to its full potential (e.g., all functions used, optimum timing plans, expansions) over a number of years.

How does one judge whether or not this definition has been satisfied; that a system is successful? There are quantitative measurements such as changes in travel time, stops, fuel consumption, accidents, and similar measures-of-effectiveness (MOE). Evaluations addressing these MOE's, however, are usually conducted shortly after system start-up when the traffic control system is performing at its peak. Under these circumstances, very few, if any, systems will ever be classified as failures. Over time, even if the timing plans and control strategies are not updated, the traffic system will generally provide more benefits than if no system existed.

A system's success (or failure) requires a qualitative assessment. Perhaps the best measure is the attitude of the people who interact with the system -- the operators, maintainers, management personnel, and decision makers. If these people have faith in the system and its capabilities, then the system and the system process has most assuredly been a successful one. On the other hand, if there is a prevailing sense that the system has not fully achieved (or perhaps cannot achieve) its traffic control and management objectives -- that it is necessary to work around the system rather than working with it -- then one is likely dealing with a system failure. In the final analysis, successful systems (as well as failures) are in the eye of the beholder.

HUMAN RELATIONS

The traffic control system process requires the talents of many people. Excellent human relations are therefore essential to a system's success. In fact, this may be the most critical aspect of the system process. If the various participants cooperate throughout the process, then a successful system is almost assured. On the other hand, when the relationships between individuals disintegrate and they start to work at cross-purposes, the success of the traffic control system is seriously endangered.

From a management perspective, this dependence on the social behavior of different individuals can be a bit unsettling. After all, the most critical element of the system process is also the least controllable. There are, however, a number of general principles, summarized in table 1, which can help to promote and maintain good human relations.

In essence, the chances of a system being successful are greatly enhanced when all the key individuals and their organizations share a common goal (i.e., a successful system) throughout the process, approach problems and disagreements in a reasonable and "good faith" manner, and are confident in each other's capabilities. Unfortunately, such a cooperative effort does not always occur. This absence of good human relations can be attributed to a variety of causes, including:

- Poor communications between people and organizations which, in turn, leads to misunderstandings. It is noted that face-to-face contact is very beneficial in this regard. It permits both parties to get a better feeling for what the problems are, to approach the problems in a more reasonable manner, and to get instant feedback; which written correspondence doesn't provide.

- Insufficient knowledge, experience, and/or information on the part of key individuals (e.g., designers, contractors, inspectors, project managers, decision makers, and other persons with the authority to provide formal approvals).

- Persons in a position of responsibility without the appropriate authority.

- Lack of continuity of key personnel throughout the process.
- Significant differences of opinion as to what is required from each organization involved in the process (e.g., different interpretation of specifications).

As is discussed throughout these guidelines, many of the above-noted problems can be minimized if the formal elements of the system process (e.g., written agreements, contract documents, qualification/selection procedures) are developed in a careful and thorough manner. It must also be recognized that there will always be a few individuals and organizations in this world who, by their nature, are mistrustful of others, inflexible, unfair, dishonest, and have little or no regard for the rules of the process. Should any of these persons get involved in the system process, then the existence of thorough and well-written documents becomes even more important.

A word of caution regarding good human relations. Compromise is essential; but this does not mean blindly acquiescing to any ideas and interpretations which are different than yours. One should not "give in" merely for the sake of maintaining harmony. Otherwisé, the other entities involved in the system process --contractors, supervisors, reviewers, funding organizations, etc. -- may take advantage of your good intentions, with the likely result that the system will not be successful.

CONTINUITY

System success is often enhanced when the same people are involved throughout the system process -- for example, the owner's project manager is designated at the beginning of the planning phase and continues throughout design, implementation, and operation of the system; operations and maintenance staff are involved during the design and implementation phases; the system designer also provides engineering assistance during construction; and the contractor's/system manager's on-site representative remains the same throughout that organization's involvement. Such continuity fosters a strong sense of commitment to the system, and helps to establish consistency in decision making and project management.

Continuity can also promote good human relations. Over time, the key individuals are able to establish a good rapport and become more empathetic and cooperative. It is noted, however, that there have been some instances where continuity had the opposite effect -- the relationship between two key individuals

Table 1. General principals for good human relations.

(Adapted from Reference 7)

- EMPATHY - In all dealings with people it is helpful to practice empathy -- placing oneself in the shoes of others and viewing the problem as they do. Use of empathy requires listening carefully to what others are saying and responding to their thoughts and needs in a reasonable manner. Determine what others really believe, why they believe this way, and why they act as they do. Understanding others paves the way for selecting the best approach for dealing with disagreements or attitude problems.

- HONESTY - Be truthful in all dealings with others. When issuing a decision or making a request, clearly state the reasons behind it. When asking for help and information, admit unfamiliarity and inform the person asked why the information is needed and how it will be helpful. Clearly present the facts. Also, be consistent -- let people know what to expect.

- INDIVIDUALITY - Approach people as individuals and not as stereotypes. Remember that every person has his/her own individual collection of ideas, habits, and ways of thinking. The cooperation and commitment that is received from others is dependent to a large degree on the ability to convince them that their competence is recognized and needed.

- THOUGHTFULNESS - Regard for the circumstances and feelings of others is essential to establishing a climate where people are willing to dedicate themselves to the common goal of a successful system. Keep in mind that people have pride in their abilities and in the work they perform. Show respect for the opinions and talents of others. Let people know that their efforts are appreciated. Be tactful -- for example don't start a conversation or meeting with individuals by criticizing or belittling their work.

- POSITIVE THINKING - Show confidence in the system, the system process, and in the abilities of those with whom you are working.

- FLEXIBILITY - Recognize that circumstances change. It is important to be flexible in one's thinking so that if a new idea or different approach is suggested during the system process, it is given full consideration and a fair decision is rendered. An idea should not be rejected just because it is novel or is not in accordance with the formal requirements of the project. It is conceivable that the facts and circumstances controlling the original decisions may have changed, or the requirement may be impractical. (At the same time, digressing from the written controls should not be taken lightly).

continually deteriorated to the point where the system process came to a near standstill, and it became necessary to have one or both persons replaced, and to begin the human relations effort anew.

Continuity should not be confused with dependence. The system process can be significantly disrupted and even halted should a key person leave or otherwise be unable to continue. It may therefore be beneficial for organizations to have a contingency for such an occurrence -- other individuals (e.g., supervisors, assistants) who have been involved in the process to some degree, and who have a cursory knowledge of the departed person's responsibilities and current activities. In the event the key person does leave, one of these "back-up" individuals can temporarily step in until a permanent replacement is found and trained, with minimal disruption to the process. Additionally, as is discussed in subsequent chapters, complete and thorough documentation of all system phases and of the system itself can also minimize the impact of personnel turnovers.

RESPONSIBILITY

Traffic control projects involve numerous individuals and organizations, each with specific functions and responsibilities during the system process. It is essential, however, that there be a **single** institution which is ultimately responsible and accountable for delivering to the agency a fully operational traffic control system. Merely stating in a contract or agreement that a specified organization has this responsibility is not sufficient. Concomitant with an assignment of responsibility must also be the necessary authority and flexibility to control and manage the risks associated with this responsibility. Furthermore, the responsible entity must possess the necessary system qualifications and experience to successfully manage the system process.

MANAGEMENT OF COSTS

As previously noted, traffic control systems provide a cost-effective solution to many traffic flow problems. Cost effective, however, does not necessarily mean inexpensive. Traffic control systems often represent a significant investment, and it is a manager's responsibility to minimize these costs wherever feasible. Great care must be taken to ensure that costs are not reduced in the wrong areas.

Figure 1 represents the distribution of total costs as expanded over the life-cycle of a typical system project. System planning and design represent the smallest expenditures, yet the work required during these phases is frequently trimmed or deferred in an attempt to save money. As shown in figure 2, the engineering performed and the decisions made during the planning and design phases of the system process have the greatest impact on total system costs. Good, as well as bad or incomplete, planning/design efforts will have a ripple effect throughout the system process. Accordingly, it is unwise to cut back on these early phases. Instead, additional funds should be allocated to properly plan and design the traffic control system. As is discussed in subsequent chapters of the guidelines, this investment will generate significant savings during the construction and the operations and maintenance phases such that total life-cycle costs are reduced.

SYSTEM PERFECTION

The system process is an attempt to approach perfection. But like most human endeavors, it often falls a little short. Those individuals who are involved in the system process must recognize and accept this fact.

A traffic control system is a very complex entity, consisting of numerous technologies (e.g., field construction, architectural, computers and other specialized hardware, software, etc.), depending on several divergent processes, and involving a large number of individuals. The chance that some sort of "failure" will not occur during the system's life is infinitesimal. Procedural and technical problems are to be expected.

While perfection may not be possible, it remains a worthwhile goal for which to strive. It is hoped that the guidelines presented so far and in subsequent chapters will reduce the number of failures, minimize their impact, and bring future traffic control systems closer to perfection.

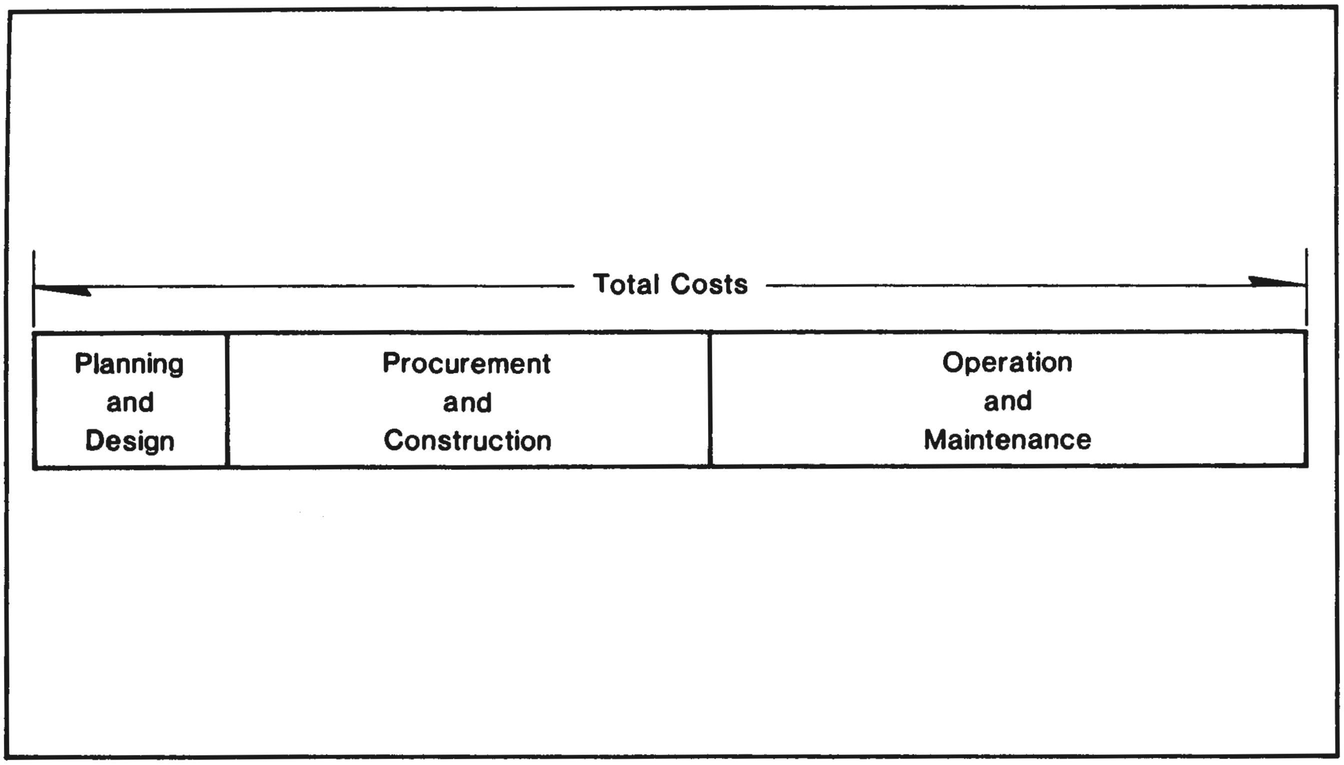

Figure 1. Life-cycle cost distribution.(7)

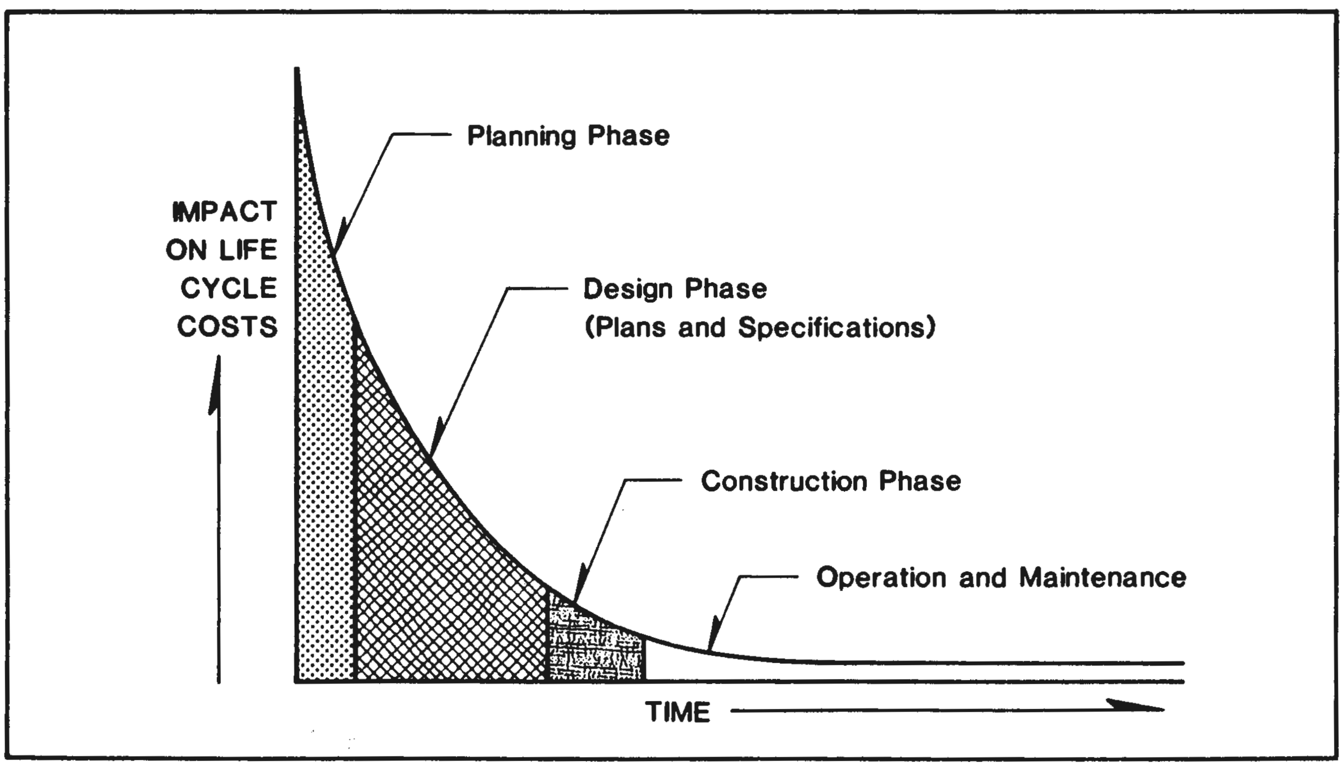

Figure 2. Influence over system costs.(7)

3. SYSTEM PLANNING

The process of implementing and managing a successful traffic control system begins with careful and comprehensive planning. This initial phase, which is often referred to as a feasibility study or traffic engineering analysis, has three primary objectives:

- System Feasibility - to determine the "best" system in terms of meeting the traffic control needs in a cost-effective manner, and balancing the operational and maintenance requirements with the availability of personnel and budget resources. Integration of the traffic control system with other transportation management functions must also be analyzed.
- System Process - to determine how the system will be procured, implemented, operated, maintained, and expanded.
- Operations Plan - to prepare a document that will serve as the guide for conducting subsequent phases of the system process, including the system's operations and maintenance.

The Federal-Aid Highway Program Manual 6-8-3-4 states that "traffic surveillance and control system projects shall be based on a traffic engineering analysis", and that the "analysis should be on a scale commensurate with the project scope".(4) All of the elements listed in table 2 should be considered regardless of the size of the system. The difference between system projects lies in the depth of the analysis and the extent of documentation.

INSTITUTIONAL COORDINATION

Nearly all system projects involve numerous organizations and multiple levels of government, and each of these institutions (table 3) will approach the project and the system from various perspectives. Traffic control systems are often significantly different from other projects to which the various organizations may be accustomed. Computerized systems are based on software and specialized electronics as compared to the concrete and steel orientation of road and bridge projects. Thus, traffic control systems don't always fit nicely into the standard institutional framework. The

Table 2. Basic elements of traffic engineering analysis.

INSTITUTIONAL COORDINATION

SYSTEM FEASIBILITY

- PRELIMINARY ANALYSIS
  - Establish area to be controlled (short- and long-term needs)
  - Analyze traffic characteristics (existing and future)
  - Review existing system resources (staff, budget, communications, and hardware)
  - Define system goals and objectives
- SPECIAL FEATURES ANALYSIS
  - Unique or special features (e.g., back-up system, CCTV surveillance, etc.)
- ALTERNATIVE SYSTEMS ANALYSIS
  - Performance capabilities of alternative systems
  - Hardware, software, communication options
  - Implications on personnel and budget requirements
  - Life-cycle costs of alternative systems
  - System benefits and "utility"
  - Subjective considerations
  - Selection of "best" alternative

INTEGRATION OF OPERATIONS TECHNIQUES

- CANDIDATE TRANSPORTATION MANAGEMENT SYSTEMS
- SYSTEM ELEMENTS TO BE INTEGRATED
  - Control center
  - Communications
  - Interface
  - Manpower
- BENEFITS AND COSTS OF INTEGRATION
- INSTITUTIONAL CONSIDERATIONS

Table 2. **Basic elements of traffic engineering analysis (continued).**

SYSTEM PROCESS

- PROCUREMENT AND SYSTEM START-UP ANALYSIS
  - Initial implementation area
  - Staging of implementation
  - Procurement options and selected approach
  - Responsible entity
  - Construction supervision and inspection
  - Acceptance testing requirements
  - Transition from old to new control
  - Initial timing plan development and implementation
  - Funding sources and budget
  - Schedules for design, implementation and start-up
  - Evaluation
  - Public information
- OPERATIONS AND MAINTENANCE ANALYSIS
  - Additional staff required
  - Training, documentation, and test equipment
  - Development and implementation of updated timing plans
- ANALYSIS OF LAWS AND ORDINANCES
  - Compatibility with existing laws and regulations relative to system operation
  - Required legislation and regulation activities
  - Agreements for obligating funds
  - Other institutional arrangements

OPERATIONS PLAN

- SYSTEM DESIGN
  - Hardware and software design (off-the-shelf, custom, product development, etc.)
  - Design responsibility
- NEEDED LEGISLATION AND AGREEMENTS
- SYSTEM PROCUREMENT
  - Procurement approach (sole-source, two-step, engineer-contractor, systems management)
  - Special qualifications of responsible entity and other involved organizations
  - Schedule for various system elements

Table 2. Basic elements of traffic engineering analysis (continued).

- <u>CONSTRUCTION MANAGEMENT</u>
  - Identification of engineer, inspectors, and technical advisors
  - Qualifications and training of inspectors
  - Coordination with utilities
  - Acceptance testing requirements
  - Test equipment required
  - Review and approval process for contractor submittals and change orders
  - Claim procedures

- <u>SYSTEM START-UP</u>
  - System pick-up procedures
  - Timing plan and data base development
  - Evaluation of hardware, software, and system performance
  - Modifications to correct deficiencies and improve performance

- <u>OPERATIONS AND MAINTENANCE</u>
  - Maintenance and operation responsibilities
  - Dedication of needed personnel and budget resources
  - Staff qualifications
  - Training and documentation to be provided
  - Position descriptions
  - Schedule for staff recruitment and training
  - Procedures for updating timing plans and control strategies

- <u>COMMITMENT TO OPERATIONS PLAN</u>

Table 3. Organizations that may be involved in the system process.

- LOCAL GOVERNMENT
  - Elected officials and their staffs
  - Traffic engineering department
  - Signal maintenance
  - Public works department
  - Finance department/purchasing agent
  - Data processing department
  - Police department
  - Fire department
  - Corporation counsel
  - Transit agency
- STATE GOVERNMENT
  - Traffic engineering bureau
  - Construction bureau
  - Finance bureau (allocation of Federal funds)
- REGIONAL ORGANIZATIONS
  - Metropolitan planning organization
  - Regional transit authority
- FEDERAL HIGHWAY ADMINISTRATION
  - Division office
  - District office
  - Regional office
  - Office of Traffic Operations (Washington, D.C.)
- PRIVATE SECTOR GROUPS
  - Utility companies (power, water, telephone, sewer, CATV)
  - Media (radio and TV)
  - Neighborhood associations
  - Business associations

institutional aspects are likely to be even more complex with a freeway control or multipurpose (i.e., integrated) system because of the additional governmental entities and organizations (e.g., fire, police, etc.) which are typically involved.

This situation has the potential for difficulties due to overlapping responsibilities, lack of understanding, and conflicting priorities and policies. To avoid these problems, it is important that close coordination be established during the planning phase. This will permit the various agencies to develop a better understanding of the system alternatives and the recommended system's features and functions, to comprehend and appreciate the overlapping responsibilities, and to work harmoniously so that each agency can better fulfill its role. Developing a good working relationship with each involved organization during the early stages of the planning phase, and then maintaining this cooperation throughout the system process, will help ensure that the system effectively meets the needs and expectations of each agency. Guidelines for promoting institutional coordination are summarized in table 4.

Institutional coordination must remain an important concern even after the traffic control system has been implemented and is operating. Examples include the police (who may detect problems that are unknown to the system such as poor signal timing, or respond to incidents that have been identified by the system); and other governmental agencies that have roadway projects (e.g., widening, reconstruction) impacting the traffic control system.

SYSTEM FEASIBILITY

Detailed information on the methods and techniques for performing a system feasibility study is contained in several of the documents listed in the appendix. There are, however, a number of procedural guidelines which merit special consideration as discussed below.

Information

A major activity during the planning phase (as well as during system design) is the gathering of information. The data may include the features and functions of alternative systems, cost information, or the location and condition of existing

Table 4. Guidelines for institutional coordination.

- Any agency or organization that will be involved with the system once it becomes operational, should also participate in the system process throughout the planning, design, and implementation phases. A prime example is the maintenance organization, or the police in a motorist aid system.

- A contact individual within each organization should be identified and a project liaison established. This will facilitate coordination when several people within a given organization are involved. Coordination with utilities should include both marketing and engineering personnel to avoid misunderstandings which often occur when only one of the functions is represented.

- Institutional coordination may be enhanced by forming an "Advisory Committee" and holding periodic meetings throughout the system project. The purpose of these meetings would be to discuss and resolve system issues, and to acquaint participants with the overall project goals, schedule, and work plan. Although each participant may have been assigned a specific responsibility, efficiencies may be expected when the participants understand the relationship of their individual activities to the overall process and to the responsibilities and activities of others.

- Progress reports, executive summaries, and similar documents should be provided to upper management in the various agencies to keep them informed.

- Before project design and implementation begins, each governmental organization must be aware of its respective responsibilities and resource requirements. Financial, personnel, and other resource commitments should be described in formal written agreements. These agreements should also delineate responsibilities during system construction (i.e., change order process, appraisals, etc.).

- Utility arrangements (e.g., use of ducts and pole gains, leased circuits, etc.) should be formalized with a letter of understanding prior to the commitment of funds for the communications network installation. Responsibilities for testing and inspection, scheduling, and performance requirements should be carefully delineated, particularly in those cases where the network is being leased or installed by the utility company. This will allow responsibility to be affixed and correction required of the appropriate party if the traffic control system, when integrated, does not operate properly. "Handshake" agreements are also vitally important -- for example police control during controller turn-on, ramp meter enforcement, power company relations, etc.

facilities. Whatever the need, detailed and accurate information and data are essential to a successful system. General principles for their collection include:

- Gather information from the best sources. Sources include written documents (e.g., reports, plans, standard specifications, handbooks, catalogs, manuals, etc.), and knowledgeable persons (i.e., consultants, contractors, manufacturers, operations and maintenance forces). The information sought will seldom be found in a comprehensive form in one place. Multiple sources should therefore be used.

- Obtain complete, pertinent data. All the information that is relevant to the intended analyses should be collected. It must also be up-to-date. The technology of traffic control systems is continuously changing, and it is important to be aware of the latest applicable technical developments.

- Work with specific and factual information. Generalities may have one or more exceptions and assumptions may be wrong. Significant problems (e.g., construction delays, additional costs, degraded operations, increased maintenance, etc.) often occur when an earlier assumption is found to be in error. Assumptions regarding the system and the system process must be kept to a minimum, and then only based on the best available information.

- Record everything. Information obtained earlier may be needed later to verify or dispute some aspect of the system process. Organization of the data is also worthwhile.

- Employ good human relations. In fact-finding, getting good information from people requires their cooperation.

Visits and tours of operating traffic control systems can be very beneficial during the feasibility analysis. It allows the owner's staff to become familiar with the various system alternatives and develop a true sense of the characteristics and capabilities of these systems.

Analysis Scope

The traffic engineering analysis must encompass the ultimate system area. To select a system based only on the conditions and requirements of the initial implementation area may cause serious problems during subsequent expansions. For example, significant expansion costs -- the result of replacing incompatible hardware (e.g., controllers) in the expansion area -- might be avoided with another system alternative which is capable of integrating this hardware. Even worse, it might become necessary to install another type of control system, independent from the first, during a system expansion. This situation would require the system operators to know two (or more) different sets of start-up, interface, and data base procedures. Similarly, maintenance personnel would have to work with different and incompatible collections of system hardware. The selection and implementation of a traffic control system is a critical decision which the jurisdiction must live with for a number of years. Accordingly, the decision must reflect the long-term system requirements and area.

Costs

The estimated cost of each system alternative is often a major, if not the most important, consideration in selecting a traffic control system. The cost analysis must take into account the total life-cycle costs of the system over an assumed period of use (e.g., 10-15 years). While the initial construction cost is a large item that captures much attention, the cost estimate for each system alternative must look beyond the initial expenses, and also include the following costs calculated in terms of present value:

- Design, systems integration, acceptance testing, data base development, and documentation costs.
- Time and expenses of local agency staff for contract management and inspection.
- Leased lines for communication network (if appropriate).
- Operations and maintenance - both in-house and service contracts.
- Training and documentation.
- Updating signal timing plans.
- Materials (supplies, spare parts, expendables) and utilities necessary for the system to function.
- Replacement of system components during the life-cycle of the system.
- System expansion or modifications.

Many of the system costs -- design, construction, system start-up, training and documentation, evaluation, initial timing plans, etc. -- are eligible for Federal-aid highway funds. Other potential sources of funding include State and local governments, developers, and transit agencies (as part of an integrated system). The cost estimate should therefore delineate the sources as well as the amount of funding. In addition to serving as the initial identification of the funding sources, the cost estimate can also be used as the basis for discussing the funding ground rules, procedures, and long-term commitments. Attention to such matters early in the process will avoid later "surprises", and will permit ample time for negotiations when there is a lack of consensus.

System Selection

The selection of the optimum traffic control system should not be based solely on costs, nor on utility-cost and benefit-cost analyses. The operational and maintenance requirements of the selected system must also be in balance with the availability of personnel, budget resources, and related constraints. In essence, utility-cost and benefit-cost ratios are valid only if the required resources are committed to the proper implementation, operation, and maintenance of the system.

The system selection process should also encompass intangible elements including:

- Potential turnover of personnel.
- Availability of system components, number of sources for the component, ease of procurement in both the short-term and for future expansions (e.g., what happens if a single source of supply discontinues the product line or goes out of business).
- Interchangeability of components.
- Whether a component/function is being utilized in other traffic control systems, and how reliably it has performed.
- Disruption to traffic and any existing systems during implementation.
- Safety of operations and maintenance personnel when interacting with system and its components.

INTEGRATED SYSTEMS

The planning phase has typically concentrated on selecting a separate and independent traffic control system, and the traffic engineering analysis has usually been very singular in this respect. However, the installation of a computer-based traffic control system provides an opportunity to implement various transportation management systems and strategies that will work together. These **integrated systems** share all or some of the same data, or a common hardware element(s). Examples of integrated systems include:

- Transit monitoring system that provides bus location data to transit operators and to the traffic signal system which, in turn, adjusts the signal timing to provide bus preemption at the intersections.
- Other data systems or functions sharing a common communications network with a traffic control system.
- A freeway surveillance and control system combined with a traffic signal system such that signal timings on the surface streets are changed concurrently with the implementation of diversion plans on the freeway.
- Using a traffic control center to provide highway advisory information over a cable TV system.
- Integration of a traffic signal system with a lane control program such that signal timings change when reversible lanes change directions or HOV restrictions go into effect.

By eliminating redundancies between systems and using common equipment and staff to perform multiple functions, an integrated system can offer significant cost savings. For example, increasing the size, storage, and speed of computers does not appreciably increase procurement nor operating and maintenance costs. Similarly, many communications media (e.g., coax, fiber, etc.) have a large bandwidth that may be substantially underutilized if used solely for a traffic control system. Integration of two or more operations techniques into a single system can also provide enhanced management of the transportation network in ways that might otherwise not be practical nor cost effective.

The first step in developing an integrated system is to identify the individual engineering techniques and operations which are currently in use or that offer potential for improved transportation management. In addition to traffic signal control and freeway surveillance and control, other urban traffic operations which might be considered for system integration include parking advisory systems, highway advisory radio, changeable bus lanes, transit monitoring system, reversible lane control, remote traffic counting, bus stop data systems, and police monitoring systems.

The next step is to determine where the potential for integration exists. Most traffic operation techniques involve the following elements, some or all of which may be combined into an integrated system:

- Control center, including computer and peripherals and their data.
- Communications medium.
- System user interface, such as roadway detectors or variable message signs.
- Manpower for operations and maintenance.

System integration must be considered during the feasibility study. This allows the integrated approach to influence the definition of goals and objectives, the development of system alternatives, the analysis of system costs and benefits, and the consideration of operations and maintenance requirements.

System integration can be a difficult process. Given the increased number of organizations which are typically involved with an integrated system, institutional constraints may prove to be the most crucial factor. The guidelines for institutional coordination presented earlier in this chapter are particularly pertinent to an integrated approach. Additional information on integrated systems is provided in reference 2.

SYSTEM PROCESS

Another key element of the system planning phase is to define the process by which the selected system will be procured, implemented, operated, maintained, and expanded. These procedural elements (which are listed in previous table 2) are discussed in detail throughout the guidelines.

System Implementation

Traffic control systems can be very complex, expensive, and require several years to design and construct. It is therefore not uncommon to adopt a staged implementation approach, whereby the system is initially installed in a specific geographic area with expansion to other areas at a later date (e.g., a signal system initially implemented in the central business district and expanded later to include arterials); or different elements of the system are used as they come together (e.g., activation of the variable message signs in a freeway system before the ramp meters and other components are used). Any sizeable system implementation effort should be staged to maximize the returnable benefits as quickly as possible.

Other guidelines for planning the system implementation process include:

- Matching the overall scope of the system project to available funding.
- Basing the construction phasing and staged implementation on budget constraints and projected fiscal year funding levels.
- Considering delaying the installation of highly visible components until shortly before they are to be used. For example, in one freeway system the variable message signs were installed early in the project, but were not used for 3 years. This created the impression to motorists that the contract was behind schedule and that the system did not work.

Ramp Metering

Special procedural considerations are required for any traffic control system which will incorporate ramp metering. Apart from the fact that intersection signals and ramp signals both display red and green indications to regulate traffic flow, significant differences exist between these systems. While nearly all of the intersection traffic signals to be integrated into a system are existing, and the public is conditioned to their presence and knowledgeable of their intended purpose; the initial application of ramp signals within an urban area represents a new method of control where before there was none. The ramp signals themselves are also quite new. Additionally, the operation of a freeway system involves numerous organizations which usually have minimal or no involvement with a traffic signal system.

Public and institutional acceptance is vitally important if a ramp control system is to be successful. Unfortunately, such acceptance is often not easily obtained. While the system will offer significant overall benefits to the public, it may be difficult to relate these benefits to individual freeway users. Many of the drivers who will be impacted by ramp metering will only see the delay caused by the entrance ramp signals. The ramp metering system may be opposed based on the perception that the control philosophy is inequitable -- the primary benefits occur to suburbanites who get an improved trip into downtown, while inner-city residents suffer additional delay at the ramp meters. This argument has not been supported by technical analysis. Nevertheless, such opposition has acted as a constraint in the development and operation of freeway traffic management systems.

The following guidelines should be considered when planning a freeway ramp metering system:

- Involve all of the affected agencies and institutions in the process from the very beginning (Refer to the previous discussion on Institutional Coordination).

- In announcing the plans for an entrance ramp control system, inform the public and institutions about the basic reasons for initiating the system (severe congestion, inefficient freeway operation, etc.), a realistic expectation of the system's benefits to users (reduced delays and user costs), and the alternative choices that are available to the system users. How the system will respond to the allocation of available capacity in an equitable manner must also be stressed.

- Discuss with local governments how the metering will be operated (e.g., rates wll be adjusted so as to prevent severe back-ups on City streets). Also discuss the differences between diversion and non-diversion strategies, and what changes will be incorporated within the corridor to minimize the impact caused by any diverted traffic.

- Investigate the adequacy of existing legislation and warrants for the installation and enforcement of ramp metering signals, and propose any changes that may be necessary.

- Perform ramp control experiments to demonstrate the effectiveness of metering in improving traffic flow. This can be done at one or a few ramps using temporary signals (with a time clock) or a policeman. Such experiments were successfully applied in Detroit and Chicago prior to the implementation of their freeway systems.

- Implement ramp metering in small increments (e.g., 5 to 15 ramps). It is often advantageous to add ramp meters in conjunction with freeway rehabilitation/resurfacing projects.

- Expect erratic traffic operations during the initial days of ramp metering (e.g., motorists not knowing where to stop, unfamiliarity with the one-at-a-time signal operation, etc.). To minimize these problems, the procedural analysis and Operations Plan should place a major emphasis on public information. Some systems have used information pamphlets which are handed out to drivers, while others have prepared audio-visual presentations.
- Closely monitor ramp meter operation during start-up, and make appropriate adjustments should problems occur.

OPERATIONS PLAN

The final element of the traffic engineering analysis is the Operations Plan. The purpose of the Operations Plan is to document what the rest of the system process will involve, to identify any necessary institutional arrangements, to indicate the personnel and budget resources required for the proposed system, and to provide a time table for the system process. Additionally, FHPM 6-8-3-4 states that "prior to authorization of Federal-aid highway funds for construction, there should be a commitment to the Operations Plan".(4)

The level of detail of the Operations Plan will depend on the type and size of the system -- the Operations Plan for an area-wide freeway surveillance and control system being significantly more extensive than the Operations Plan for a simple arterial traffic signal system. Nevertheless, most of the items outlined in table 5 should be addressed in the Operations Plan.

The Operations Plan should be reviewed by those persons who will be involved in the various aspects of the system process, as well as by people who are experienced in undertaking traffic control system projects. Such a review can reduce the probability that an important element of the process has been omitted, assure that the needs of all involved parties have been reflected in the Operations Plan, provide advanced notification of personnel requirements (e.g., positions and salary rates), and facilitate coordination among the various individuals, agencies, and organizations that impact the success of the system.

Once the Operations Plan is adopted, any deviations should not be taken lightly. At the same time, it should not be adhered to blindly nor too rigidly, since the facts and circumstances controlling the original decisions may change at any time. When circumstances do change, the Operations Plan should be revised accordingly and submitted to all involved entities for review.

Finally, the importance of thorough and comprehensive system planning can not be underestimated. The process of developing an Operations Plan for a traffic control system project seldom involves major problems, but serious problems and failures are quite likely to arise if the traffic engineering analysis has been poorly handled.

Table 5. Outline of operations plan.

LAWS, REGULATIONS AND AGREEMENTS

- Required documents
- Required legislation and agreements
  - Other involved agencies
- Responsibilities
  - Draft
  - Legal review
  - Enactment

DESIGN

- Type of procurement
- Responsibilities
  - Owner's project manager and staff
  - Parties involved in development of plans and specifications
  - Other agencies and organizations
- Standards and specifications
  - Required (such as State specifications)
  - Others
- Data and information sources
  - Plans, maps, and inventories
  - Control equipment
  - Utilities
- Plans, specifications, and estimates--reviews and approvals
  - Comments
  - Concurrence and approval

BID/AWARD PROCESS

- Responsibility to advertise, take bids, and award
- Advertisement
  - What journals
  - Content
- Pre-bid activities
  - Pre-bid conference and attendance requirements
  - Prequalification procedures (if any)
  - Review of proposals (if 2-step process) and approval authority

Table 5. Outline of operations plan (continued).

- Bid analysis and award
  - Involved parties
  - Concurrences
  - Award authority

- Notice to proceed

CONSTRUCTION MANAGEMENT

- Project engineer

- Others on the construction management team
  - Utility coordinator
  - Technical specialists (consultant)

- Other involved entities
  - Utilities
  - Police
  - Fire services
  - Signal maintenance
  - Cable TV

- Underground clearance process

- Inspection
  - Lead responsibility
  - Others involved
  - Training

- Shop drawings, other submittals
  - Approval/concurrence responsibility and authority

- Change orders
  - Chain of command for approvals
  - Information requirements of those in chain of command
  - Timetable

- Acceptance testing (for each type of test or test item as appropriate)
  - Who develops testing procedures?
  - Testing by whom?
  - Sites (independent laboratory, signal shop, contractors shop, etc.)
  - Equipment required

- Claim procedure

- Training
  - Types of training required
  - Timetable
  - Who involved (teaching and receiving)

Table 5. Outline of operations plan (continued).

- Site travel
- Budget requirements

• Documentation
  - Types of documentation required
  - Submittal requirements
  - Timetables

• Test equipment

SYSTEM INTEGRATION AND START-UP

• System pick-up procedures

• Timing and data base development (the responsibility, format, and timetable for each item should be stated)
  - Inventory data
  - Count data
  - Encoding and running signal timing program (e.g. TRANSYT 7-F)
  - Review of timing program results
  - Encode timing in the appropriate data base format and input to system
  - Evaluate new timing plans (field evaluation) and fine tune

• Acceptance test of integrated system
  - Exercising functions of system
  - Contractor or consultant assistance

• Evaluation (agency forces or consultant)
  - Data gathering
  - Data analysis
  - Draft report
  - Review draft report
  - Accept final report
  - Print and distribute report
  - Public brochure

SYSTEMS OPERATION

• Operators and responsibilities
  - Number required (on board and additional)
  - Qualifications (position descriptions)
  - Recruitment (including timetable)
  - Training (initial and ongoing)
  - Working hours (regular)
  - Working hours during special events and emergencies

• Updating timing plans and control strategies

Table 5. Outline of operations plan (continued).

- Counts
- Develop timing plans
- Encode timing plans and fine tune

SYSTEMS MAINTENANCE

- Contract maintenance
  - Development of specifications
  - Review process
  - Approval and award
  - Inspection of maintenance contractor

- Agency forces
  - Number required (on-board and additional)
  - Qualifications (position descriptions)
  - Recruitment of additional staff (including timetable)
  - Training (initial and ongoing)
  - Spare parts inventory (initial and ongoing)
  - Maintenance equipment
  - Working hours, call-in policy, etc.
  - Response and repair time policy

OVERALL SCHEDULE OF SYSTEM PROCESS

COMMITMENT TO OPERATIONS PLAN

4. SYSTEM DESIGN

The system design phase involves taking the recommendations and decisions made during the planning effort; further detailing the system hardware, software, and functional requirements; and then translating this information into contract documents. The plans, specifications, and quantity estimates combined define the work to be performed. They also govern the official relationship between the contractor and the agency for whom the system is to be built.

The accuracy, completeness, and quality of the contract documents will determine, to a large degree, whether a traffic control system will be a success or failure. Many of the problems that occur during system implementation and start-up can be attributed to errors and oversights committed during the design phase. These design flaws can include essential components not being addressed in the contract documents, incomplete or erroneous information, inadequate testing requirements, ambiguous statements which permit widely disparate interpretations, or a combination. Whatever the scenario, the root of many construction delays, cost overruns, and operational and maintenance problems rests with system design.

DESIGN APPROACH

There are three basic approaches on which to base the design of a traffic control system:

- Off-the-shelf.
- Custom.
- Experimental.

Off-the-Shelf

As the name implies, this type of system is comprised of standard "off-the-shelf" components (e.g., field communications units and modules, central computers, field microprocessors, traffic software, communications processing, etc.) which have been thoroughly tested in an operational setting and are readily available from a system manufacturer. These prepackaged systems are typically easier to install and have lower initial implementation costs as compared to the other approaches. Furthermore, basing the design on an off-the-shelf system will significantly enhance the possibility of a smooth and relatively trouble-free implementation process.

An inherent deficiency with off-the-shelf systems is that they may not provide all of the features and capabilities which are required or desired by the owner. What the standard system package offers is what one gets -- no more, no less. Another problem with these systems is that some of the components may be proprietary -- that is, the rights are owned by the manufacturer. Once a particular off-the-shelf system has been installed, the owner is essentially tied to the system supplier for component replacements or expansions, thereby eliminating competitive procurement. The documentation for some proprietary systems also tends to be incomplete (to protect the supplier's investment) and can be difficult to use.

Custom

A "custom" system is one that is based on existing technology, proven software, and off-the-shelf hardware; but one or more of these system components must be modified (i.e., customized) to satisfy the needs and desires of the owner. The modifications are relatively minor in that they are still within the realm of the existing state of the art in traffic control. A prime example of a custom system is a UTCS-based signal system where the base-line software package is modified to provide expanded and additional features. The basic control premise nevertheless remains the same. (Note - UTCS stands for "Urban Traffic Control System", and consists of two baseline software packages available from the Federal Highway Administration.)

Custom systems are typically more expensive than off-the-shelf systems, but they also provide additional features. Furthermore, being less proprietary, they offer the user more flexibility with respect to implementation and expansion. The risk of encountering problems during system implementation increases as more and more customizing is required. Accordingly, the design documents must address any new features and/or modified system elements in a thorough and clear manner.

Experimental

An experimental system is one that truly advances the state of the art. One or more of the primary system elements (e.g., software, communications processing, field hardware) involves a technology or an approach which is new to traffic control, or a current technology that has been significantly altered or modified. Examples of experimental systems include the initial installations of new control concepts (e.g., the first applications of UTCS-Enhanced, 1.5 generation control, distributed processing), and of new hardware (e.g., fiber optics cable, environmentally - hardened modems for use in the field, etc.). Given the infrequency of their installation and their unique location-specific requirements, many freeway control systems also fall into the experimental category.

Several experimental systems have experienced adversity during the system implementation phase. These problems have included project delays, cost overruns, contractor claims, and even litigation. Given the difficulties typically encountered when developing and integrating hardware that must satisfy new functional/environmental requirements, and the risks normally associated with developing and debugging new software, some sort of problem is almost inevitable with an experimental system. High-quality contract documents and expert engineers and contractors are a must when implementing such a system. But even more crucial to the system's success is establishing and maintaining good human relations -- implementing the system in a spirit of mutual cooperation and confidence, and approaching any problems that do arise with patience and reason.

Discussion

Many literature sources which describe or evaluate a specific system, as well as some general system references, recommend that the design of a system be based on existing technology, proven software, and off-the-shelf hardware which has been tested in an operational setting. This design approach undoubtedly reduces the risk of potential implementation problems, and may enhance the reliability and maintainability of the system. There is, however, a dichotomy associated with this design approach in that it conflicts with the dynamic nature of traffic control systems.

The state of the art in traffic control has steadily advanced over the past several decades. System features and functions have dramatically improved and system reliability has been enhanced. These advancements have resulted from a willingness to "tamper" with proven technology. If the transportation engineering profession had not been willing to try the untried, we would not have computerized traffic control today.

Each truly new approach necessarily involves an element of risk and uncertainty for the system purchaser, the design consultant, and the contractor. Even the transfer of an existing technology from another discipline to a traffic control application poses risks. Furthermore, the degree of risk and uncertainty may be difficult to gauge, even for experts and the highly experienced. New approaches and technologies in traffic control systems have not always been immediately successful, and similar problems can be expected to occur in the future. It is important to remember that the transportation engineering profession has learned from these "failures", and has made the necessary adjustments and corrections such that subsequent applications of the new technology have brought successful results. Furthermore, good contract documents, coupled with cooperation and commitment to a common goal, will minimize any problems.

System design must reflect the specific needs of the jurisdiction and its motorists. In many instances, utilization of existing technology and off-the-shelf hardware will be more than adequate. But such a design approach should not be applied indiscriminately. There will be applications where the system requirements call for new technologies and innovative approaches. It will then be necessary to balance the potential benefits of enhanced traffic control with the corresponding risk of encountering significant problems during the system process.

SYSTEM PROCUREMENT

One of the elements of the planning phase is to determine the approach and procedures for procuring and implementing the system. There are four basic approaches which may be used to procure a system, each with its respective advantages and disadvantages:

- Sole-source.
- Engineer/contractor (turn-key).
- Two-step procurement.
- Systems manager.

Regardless of which approach is used, it is essential that a single entity be responsible for providing a fully operational traffic control system to the owner.

Merely stating that "the Contractor is responsible....." in the specifications is not sufficient. Concomitant with the assignment of responsibility must be the authority to control and manage the risks associated with this responsibility. Specifically, the responsible entity should have systems experience and, as a minimum, be given direct control over the following activities:

- Software development.
- Selection and procurement of software dependent hardware (e.g., computer, intelligent communications equipment, etc.).
- System integration.
- Procurement and installation (if turn-key contractor); <u>or</u> design and inspection (if systems manager) of all other system related hardware (e.g., field communications units, communications mode and media).

Dividing these responsibilities among different entities can cause serious procedural problems, particularly if it becomes necessary to identify an accountable party to correct a specific deficiency. For example, consider a project where the system designer has also developed the software, but the contract for system installation requires the contractor to use this software <u>and</u> to provide a fully operational system (i.e., the contractor is designated as the responsible entity). If the software doesn't function properly, who is at fault and, accordingly, who is responsible for making the system work? The contractor can claim that he/she was required to use "defective" software and it is therefore the designer's problem. On the other hand, the designer can claim that the contractor has full responsibility to provide an operational system and must therefore correct any and all deficiencies. Resolving such questions and similar conflicts of responsibility can greatly impact the system process in terms of delays and extra costs.

Sole-Source

With a sole-source approach, the contract documents simply call for the end product by the manufacturer's name. This approach is typically used for off-the-shelf systems where the owner knows that a specific system is desired. It is also used for expansions of proprietary systems. The manufacturer's specifications are used outright, or they serve as a basis for contract negotiations between the owner and the supplier. The contract is then awarded to the manufacturer without competition.

Because it typically involves a standard off-the-shelf system, sole-source procurement usually results in a smooth and problem-free implementation process. It also eliminates competitive bidding. Thus, the sole-source process can be used in Federal-aid projects, and in many city and State procurements, only if there has been a finding that it is more cost-effective than a competitive low-bid process.

Engineer/Contractor

This procurement approach has traditionally been used within most transportation agencies. Typically, an engineer prepares a single set of contract documents (PS&E) for the proposed system. The contract documents are then tendered, bids are received from contractors, and the project is awarded to the lowest responsive bidder. The winning contractor is responsible for providing a complete and fully operational system, including furnishing and installing all hardware and software, system integration efforts, training and documentation, and, in some instances, the development and implementation of timing plans. The engineer often continues his/her activities during system installation by monitoring the contractor's progress, reviewing contractor submissions, participating in the system testing, providing interpretations of the plans and specifications, and developing system timing if not performed by the contractor.

With the engineer-contractor (and the two-step) approach, there is only one contract to prepare and administer. However, no single prime contractor possesses the necessary experience and qualifications to perform all of the work included in the typical turn-key systems contract. For example, electrical contractors do not have programmers on staff for developing and integrating software. Similarly, a systems firm is not capable of installing conduit and pulling cable. The prime contractor for a turn-key systems project must therefore subcontract a significant portion of the work, and the subcontractors may in-turn subcontract portions of their work.

The prime contractor is contractually responsible for the work and the actions of the subcontractors and equipment suppliers. How well the prime (i.e., responsible entity) coordinates and manages its subcontractors is therefore critical to the project's success. However, administering multiple layers of subcontractors and suppliers is difficult even under the best of circumstances. It requires good human relations, technical expertise, and familiarity with the type of work being performed by the subcontractors. A traffic control system project, particularly one involving a custom or experimental system, encompasses a wide range of technologies, equipment, construction techniques, and related services. The prime contractor may not have sufficient knowledge of some of these elements to select appropriate or qualified subcontractors, and then to effectively administer and control their actions. As is discussed in chapter 5, some form of prequalification of subcontractors may be helpful in this respect.

Another important consideration with a turn-key project is what type of firm should be prime. Often, the majority of the project's dollar value involves field construction and electrical work, in which case it may be best to have an electrical contractor as prime. However, with this arrangement, the owner may not be able to deal directly with the system subcontractor -- the system firm hired by the prime contractor to develop the software and integrate the system. Interaction between the owner and the organization developing the system software is very important for success.

This potential problem can be resolved by requiring that a system firm be prime. However, this arrangement may also prove troublesome. Most of the system firms active in the traffic control market today are engineering firms. Many of them have little or no experience as a prime contractor of a large construction project. Furthermore, these systems firms have very few capital investments (e.g., rolling stock, construction equipment, etc.) which, in turn, may make it difficult for them to obtain the necessary bonding.

Two-Step Procurement

The two-step procurement is essentially the engineer/contractor approach combined with a formal contractor prequalification process. The two-step process has been successfully used to ensure that only those contractors with previous systems experience and the resources necessary to complete the project may submit bids.

In the first step of the formal two-step process, the plans and functional specifications, along with a Request for Proposals (RFP), are submitted to contractors. The RFP should include a statement that the two-step method will be used, identify the proposal requirements and the evaluation criteria, and describe the process for reviewing the technical proposals and for notifying the contractors as to the acceptability/unacceptability of their proposals (e.g., will the final determination be made solely on the basis of the proposal as submitted; or will offerors be permitted to supplement their proposals with additional information based on discussions with the reviewing agency).

Interested contractors submit technical proposals responding to the requirements of the RFP and the contract documents. The information may include:

- Complete detailed financial statement.
- List of references for similar projects.
- Detailed plan for performing the proposed work.
- Names and experience of key personnel (e.g., superintendent) and their availability.
- Description of facilities.
- Listing of proposed hardware and software, including appropriate catalog cuts.
- Items of work to be subcontracted, to whom, and the qualifications of each subcontractor.
- Preliminary work schedule.

It is emphasized that cost data are specifically excluded from this submission. Additionally, the reviewing agency must not disclose any trade secrets nor proprietary information that may have been included in the proposals.

The prequalification information is reviewed and evaluated against the specific criteria contained in the RFP, and a determination is made of qualified proposals. In the second step, a formal request for bid is issued only to those contractors who submitted qualified proposals. The standard bid/award process of the engineer/contractor approach is then used.

There are some potential drawbacks associated with the formal two-step process described above. Some qualified system contractors may decline to submit a prequalification package. One concern is that preparation of a technical proposal requires a level-of-effort that is normally performed <u>after</u> the contract has been awarded. This effort may entail a substantial engineering cost that can only be recovered by the successful bidder.

Another problem is that the formal two-step process requires exposure, <u>before</u> contract letting, of the specific equipment manufacturers and techniques proposed to meet the requirements of the specifications. In view of the economy and pricing structure of various manufacturers, a vendor that has an attractive pricing structure during the preparation of the proposal may not be competitive at the time that the bids are actually accepted. Considering that the project is eventually awarded based on low-bid, the two-step process could lock a contractor into a situation that, although appearing favorable at the time of the proposal, may be unfavorable at the time of contract award.

Another concern of prospective bidders is that, after they have invested the time and money to prepare a prequalification package, their submittal may be rejected for an unintended technicality. Accordingly, it may be worthwhile to request additional information from offerors of proposals that are reasonably susceptible of being made acceptable. This approach may also prove beneficial to the overall system process. If prospective contractors know they will have a "second chance" to be prequalified for bidding, they may be more willing to identify potential problems with the contract document (e.g., a specified component that is nonexistent), or to propose an alternative that, while not in strict compliance with the specifications, will provide a better final product. It is emphasized, however, that should an exception to the specifications be permitted during the prequalification process, then all prospective bidders must be made aware of the approved exception.

A thorough review of the prequalification information is crucial to the success of a two-step process. The design proposal submitted by the winning contractor is considered a part of the contract and is therefore binding. The contractor will base the bid on his/her <u>approved</u> proposal. Should the owner desire something more or different during system implementation -- that is, something not included in the approved prequalification package -- the contractor may be entitled to additional compensation.

There are several variations on the two-step theme. Many transportation agencies keep a current "Approved Product List". Any traffic control hardware that is installed in the jurisdiction must be on this list. The precertification process typically includes submission of descriptive literature (e.g., catalog cut, specifications, detailed drawings) and sample devices for review and testing by the agency. At least one State has included off-the-shelf distributed systems (i.e., combination of microcomputer, software, field masters, and controllers with internal coordination units) on their Approved Product List. Another State requires successful installation and operation of traffic control hardware prior to including it on their Approved Product List. New hardware and components are permitted to be used in a limited number of installations to test and determine their acceptability.

Another variation of the two-step process is a best-buy or negotiated procurement. This process is sometimes used to select design consultants, system mangers, and vendors of specialized hardware. Potential contractors submit a proposal and cost estimate for review. The agency may discuss the proposal and estimate with some or all of the submitters. The contract is then awarded to the contractor that offers the "best-buy". A negotiated procurement permits consideration of various intangibles such as previous experience, location, proposed work effort, impact on other system components, maintenance, etc. Although it is competitive in nature, best-buy requires a finding (for Federal-aid projects) that is more cost effective than the low-bid process.

Systems Manager

With this approach, a systems manager is the responsible entity. The activities of the system manager typically include design, preparation of plans, specifications and estimates (PS&E), construction engineering and inspection, software development, procurement of software-dependent hardware, system integration, timing plans, and training and documentation. The contract between the owner and the systems manager is typically a negotiated agreement for engineering services.

Instead of a single turn-key contract, several contracts for the various subsystems are prepared. Examples of these separate subsystem contracts include computer room construction; procurement of communications hardware; procurement of computer hardware; installation of sign support structures; and field electrical work (e.g., new controllers, loops, communications cable, signal displays, signs, etc.). The agency's normal procurement processes are used to procure the individual subsystems and services. In some cases, the local traffic engineering agency has procured and installed certain subsystems (e.g., controllers). The system manager administers these contracts and is responsible for integrating the various subsystems into an operating system.

A distinct advantage of the systems management approach is that the system design, software development, and system integration activities are all controlled by a single entity -- the systems manager. This provides continuity throughout the process as well as a single source of responsibility and accountability. This "responsible entity" cannot blame its problems on the designer as they are one-in-the-same. It is essential that the systems management firm be qualified to perform the various system management activities, and that it have the proper facilities for software development, integration, and testing.

Another potential benefit of the systems management approach is that the engineering agreement between the owner and the systems manager is generally negotiated. This allows both parties to jointly determine the scope of work, define their respective duties and responsibilities, develop a realistic estimate of the corresponding costs, and to fully understand what is required from the traffic control system before the work actually commences. Experience has also shown that these engineering agreements for systems management offer the owner more flexibility as compared to the more rigid requirements of turn-key specifications.

When multiple contracts are used, as they are with the systems management approach, it is critical that all necessary components be included in the various contracts. For example, if one contract covers installation of variable message signs and another contract addresses the sign support structures, then one of these contracts must also include power service conduit. Another example is the failure to include the proper type of power receptacles in either the computer room contract or in the purchase order for the computer equipment. Typically, such missing items occur in those areas where the different contracts interface with one another. Correcting such oversights often requires a construction change order which may delay or increase the cost of the system.

Putting a particular component in the wrong contract can also cause problems. For instance, the procurement of computer equipment and other high-tech items should not be included in a field construction contract. Likewise, the supplier of sophisticated systems equipment should not be required to install foundations or conduit.

Proper sequencing and coordination of the various subsystem contracts is critically important during a systems management project. Obvious examples include installing the computer hardware after the master site facility is finished; installing field communication units after any new controllers have been installed; commencing intersection pick-up after all other work has been completed; and so forth. In essence, the systems management approach demands a much higher level of effort to effectively manage the overall system project. This project management and coordination is one of the major responsibilities of the systems manager, and is a significant factor affecting the system's success.

Discussion

The "best" procurement approach depends on the type of system to be installed, the amount of work required to install the system, and the current conditions within the systems market. In general, sole-source procurement or the engineer/contractor approach (with an electrical contractor as prime) are workable for "off-the-shelf" systems. Custom systems have been successfully implemented via both the engineer/contractor (with a system firm as prime) and the systems management approaches, although systems management offers some advantages for projects involving a significant amount of customizing. Systems management or the formal two-step process will probably be best for any system which will advance the state of the art. It is emphasized that these are general guidelines. The advantages and disadvantages of the various procurement methods must be carefully analyzed within the context of the specific scope and requirements of each system project.

DESIGN ELEMENTS

The products of the design phase consist of plans, specifications, and estimates. In general terms, the plans are defined as the design drawings which graphically portray the work to be done. Specifications, as implied by the term, are written instructions which specify the materials, quality of workmanship required, and the results to be obtained. Estimates are documents which include the quantities of required materials and work, and the corresponding costs. The purpose of the contract documents is to:

- Define all elements of the work to be accomplished, thereby providing contractors a definite basis for preparing bids, and informing representatives of the transportation agency (e.g., engineer, inspectors) what the contractor is obligated to do.
- Describe the required procedures and/or end results.
- State the basis for accepting or rejecting components, subsystems, and the completed work; including testing and payment provisions.
- Provide the rules of the implementation process, identifying the involved parties (contractor, engineer, consultant) and their contractural obligations.

A common phrase used in specifications is that the contract documents "spell out the minimum requirements of the traffic control system". This may be true in a pure contractual sense. But the prudent designer will develop the specifications and the other design elements to represent the maximum requirements; for that is how the contract documents will be viewed by contractors. This is not to imply that contractors are disreputable -- although there will always be a few who treat the contract documents merely as guidelines, or worse, ignore them altogether -- it is the nature of the competitive low-bid environment.

In the free-enterprise system, contractors -- be they electrical firms, equipment vendors, system managers, or consultants -- are profit-oriented. To achieve this objective, these firms must first win projects (i.e., furnish the lowest bid), and then develop and install the specified product at the lowest possible cost.

Bids and cost proposals are based on the information and requirements contained in the contract documents. Prospective contractors will interpret these various provisions in a manner that results in the lowest possible, yet profitable, bid price. Contractors have also been known to base their bids on optimistic assumptions as to how the work will progress, interpretations that contradict the specifications but which have been approved on other projects, or recognition of a conflict or error in the contract documents that can be used to the contractor's advantage during construction.

If a contractor prepares a bid to cover all possible risks (i.e., worst-case scenario) or includes costs for "additional" items or work, then the bid will most likely be greater than the competition's and the contractor will lose the job. It is totally irrelevant that this additional work was intended by the designer or even that it will be required sometime during the course of the contract. If the work or item is not clearly and explicitly addressed in the contract documents, prospective contractors have no incentive to include the costs of this work in their bids.

Once the contract is awarded, the bid becomes the contractor's price (cost plus profit) for furnishing all materials and performing all the work. Accordingly, the contractor will want to manage the project and construct the system using the same interpretations and assumptions on which the bid was based. If this interpretation is different from the interpretation of the transportation agency -- and this has been the case in countless instances -- then the contractor will generally demand additional compensation for extra work. Furthermore, the contractor will likely be entitled to the extra money if the contested items and work were not specifically included in the original scope of the contract documents, or if the contract documents were in error regarding the items.

It is extremely important that the contract documents define all the work that must be accomplished; avoid ambiguities; and provide a singular interpretation of the responsibilities and risks of the contractor, the transportation agency and other involved parties. Whenever the contract documents leave room for doubt as to what is meant, the potential for problems is great. Furthermore, the courts will strongly favor any reasonable interpretation proposed by the party who did not prepare the contract documents (i.e., the contractor). The reasoning is that the preparer had ample opportunity and time to clearly spell out what was intended. If the designer was not successful in this endeavor, then the advantage of interpretation goes to the contractor.

Another important consideration is that a contractor is not a warrantor of contract documents furnished by the transportation agency. The contractor does not guarantee their sufficiency. The general rule of law is that when a contractor is required to build according to the contract documents prepared by the transportation agency (or its designated representative), the agency impliedly warrants that if these plans and specifications are complied with, then the finished work will be adequate. The contractor can not be held responsible for the consequences of errors and omissions in the plans and specifications.

Various agencies, recognizing this general principle of warranty of contract documents, have sought to shift the warranty by requiring the contractor to visit the site, check plans, identify all requirements of the work, and assume complete responsibility for the work. Such clauses are unfair. Furthermore, these requirements do not impose on a contractor the obligation to confirm the adequacy of the contract documents for accomplishing the agency's purpose.

SPECIFICATIONS

The discussion herein is aimed primarily at the development of specifications for a system procurement/construction contract which is let to bid. It is emphasized that the guidelines for successful specifications also apply to any written agreement or contract that is utilized during the system process, including requests for proposals; an engineering service agreement for design, construction engineering, and systems management; intergovernmental agreements; agreements with utility companies; and maintenance service contracts.

The project specifications are the legal performance standards by which the transportation agency may enforce quality control. Well-written specifications will provide for uniformity and predictability of the product and of the process.

Specifications consist of two basic elements. The general conditions define the business, legal, and financial relationships between the agency, the engineer, the inspectors, the contractor and the subcontractors. They also state the effect of public laws on each. In other words, the general conditions address the procedural aspects of the system implementation phase.

The second element of the specifications are the technical requirements. The technical requirements are detailed instructions to the contractor or equipment vendor, stating what materials to use, how to employ them, what services to provide, what results are desired, and how the work will be tested and accepted. In essence, this element of the specifications provide for the technical development and control of the work.

Specification writing is perhaps the most critical element of the design phase. Specifications must always be:

- Complete and correct.
- Definite and certain.
- Economically sound.
- Fair and just.

Additionally, system specifications must also provide for testing and acceptance, and for training and documentation.

Complete and Correct

The specifications must clearly state the desired result. This may entail detailing the functions of the system, the methods and materials to be used by the contractor, or a combination. It is essential that the specifications address all aspects of the desired system and its many components, and of the implementation process. As previously discussed, the contractor will most likely view the specifications as the maximum requirements -- if the specifications don't specifically delineate a system function, component, nor procedural requirement, then it doesn't exist.

Simply stated, if a system function or component is needed or wanted, include it in the specifications. All too often agencies have not gotten what they desired (or else had to pay extra) simply because the item or feature was either not defined in the technical specifications, or the description was incomplete. For example:

- A software specification defined the functional requirements of the system data base. However, the specifications did not address who was responsible for obtaining and compiling the necessary data, for converting the information into the appropriate data base format, for entering the data base into the system, and for performing error checking and fine tuning such that the system operated properly. The agency had to modify the design consultant's contract to include data base development. Furthermore, the contractor filed a claim for delays in receiving the completed data base and for extra work to correct data base errors.

- A specification required the system software to control various types of controllers, but did not address the fact that the jurisdiction changes phase sequence by time-of-day. As a result the system has problems with this particular function.

- A specification for a piece of test equipment addressed its functions (i.e., "simulate central as well as remote inputs and outputs"), but said nothing about the size or weight. The test equipment serves little useful purpose because it is too heavy and cumbersome to be carried in the field by maintenance personnel.

- A jurisdiction had to issue a change order involving extra funds for round span and mast-arm poles. The specification did not address the shape of the pole and the contractor had based his bid on supplying a multisided pole.

Conflicting or inaccurate statements regarding an item or feature are just as troublesome as failing to address the element. For example, a specification contained one article which required Remote Communication Unit (RCUs) to be shelf-mounted in new and existing controller cabinets. However, another article in the same specification required that add-on cabinets be installed to house the RCUs. The contractor based his bid on the first requirement (which was less expensive than furnishing and installing new add-on cabinets), but the agency wanted the add-on cabinets. The conflict resulted in a change order being issued to the contractor for the add-on cabinets.

The technical specifications for hardware should address functional requirements, material standards, and environmental considerations to ensure reliability. While requiring high quality equipment, care should also be taken to ensure that the hardware can be obtained from more than one source. Single source requirements prohibit competitive bids which can increase costs. Furthermore, as previously discussed, a sole-source procurement may not be permitted under Federal, State, or local requirements.

The software specifications, being so crucial in terms of costs and system success, are especially important. Being functional in nature, they are also probably the most difficult to write. After all, complex traffic control software is subject to far fewer design standards and criteria than signal or highway designs. The software specifications must emphasize performance; and every necessary and desired software feature and system function must be addressed. The software specifications should also require a structured approach to software development, documentation, software quality and reliability, and demonstration and testing. However, they must not go so far as to actually "design" the software -- that is, the software specifications should not include flow charts, programming procedures, and similar constraints. If these types of details are included, the agency assumes responsibility for their completeness and accuracy, and the accountability of the contractor is lessened.

Technical requirements for many system components are addressed in the references listed in the appendix. It is emphasized that these and similar documents are only guides. It is the responsibility of the designer to tailor the technical specifications to the local requirements and desires, and to the system technology involved.

The adequacy of the procedural aspects is just as important as the technical requirements. The general conditions of the specifications should address the items discussed below.

Definitions

A great deal of refinement in terminology and meaning must be incorporated into the specifications. In addition to definitions of the standard terms for construction projects (e.g., Engineer, Agency, Contractor, Written Notice, etc.), definitions of all special terms or terms which may not have a precise meaning must also be included. These might include System Manager, Integration, System Timing, Data Base, etc.

Superintendence

A requirement that the contractor or systems manager (i.e., the responsible entity) have a permanent on-site representative or superintendent throughout the project can prove very beneficial. The daily face-to-face contact between the agency's project manager and the responsible entity's superintendent can promote the good human relations which are so essential to a successful system. A full-time superintendent with systems experience and knowledge will likely increase the contractor's bid price/system manager's fee. But the superintendent's presence and expertise may save money in the long run, particularly if the system project is large and complex in scope, or advances the state of the art.

The specifications regarding the on-site representative should include the following considerations:

- Experience and qualifications of the superintendent.
- Authority of the superintendent to receive and act upon directions given by the engineer, and to sign official project documents (e.g., change orders).
- Submission of the proposed superintendent's resume and approval by the agency.
- Requirement that the superintendent be on-site during the project and that the superintendent not be changed without the agency's consent (thereby assuring project continuity).

Engineer's Authority

Just as the superintendent represents the contractor or systems manager, the engineer represents the agency during the system implementation process. The specifications should clearly state the engineer's responsibilities and authority, including:

- Interpreting all provisions of the specifications and drawings.
- Monitoring work for safety.
- Stopping work whenever necessary to ensure its proper execution.

- Rejecting all work and materials which do not conform to the requirements of the specifications.
- Determining quantities for progress and final payments.
- Deciding questions which arise in the execution of the work.
- Determining, as required, the adequacy of the contractor's methods, equipment, and plant.
- Instructing the contractor to apply forces to such parts of the work as may be reasonably necessary to ensure the proper and continuous progress of the work.

When a systems manager is used by the agency, his/her authority should also be delineated in the specifications.

Responsibilities and Risks

The specifications must allocate risks to the party(ies) best able to control them. For example, a contractor can be required to contact utilities to mark their underground facilities; and should the contractor then damage a utility that was marked in the field or on the plans, the contractor can be held responsible for its repair. However, the contractor is generally not responsible if the existing condition was not identified or was not readily apparent.

System projects often require a few years, or even longer, to construct, test, and accept. Problems can arise when components that were installed during the early stages of construction are not operational at the time of final system testing or acceptance. Thus, it is essential that the specifications clearly state when and under what circumstances a component is accepted, and at what time maintenance responsibilities shift from the contractor to the agency. Merely stating that the contractor is responsible for all hardware until final system acceptance is unfair, and is likely to cause problems. First of all, there are many unknowns which make it difficult to accurately estimate the cost of extended maintenance. Furthermore, in order to reduce the bid price, the contractor will likely assume that minimal or no maintenance will be required. Should maintenance or repair of a component become necessary some time after its installation and initial testing, the contractor can be expected to contest this requirement. As an example, loops were cut early in a project. When the time of final system acceptance arrived (several years later), some of the loops were inoperable and their repair was included on the punchlist. The contractor successfully argued that he should not be held responsible for the loop repairs because the loops were installed in accordance with the agency's specifications, the installation was witnessed by the agency's inspectors, satisfactory workmanship was proven when the loops were tested, and the contractor had no control over the traffic conditions nor pavement containing the loops during the period following loop installation and testing.

As a general rule, maintenance responsibilities for a particular component should transfer from the contractor to the agency at the time the component is successfully tested and accepted. If it is possible to establish a firm cost for maintaining a component over time (e.g., computer maintenance agreement, separate bid item based on an estimated number of hours or occurrences, etc.), then extending the contractor's maintenance responsibilities throughout the system project to final acceptance, and even beyond, may be feasible. Other maintenance considerations and responsibilities which should be defined in the specifications include:

- Safeguarding work against damage or destruction.
- Remedial (i.e., replacement) vs. preventive maintenance.
- Response time following notification of malfunction.
- Means by which contractor can be contacted regarding maintenance problem.
- Maintenance of existing signal coordination.
- Exemptions, if any (e.g., accidents, floods, lightning, etc.).

Warranty and Guarantee

Even after a hardware component has been accepted and the maintenance responsibilities have shifted, the specifications should provide that the contractor will be responsible for guaranteeing any and all electrical and mechanical equipment (e.g., controllers, communications interface, detector amplifiers, signs, etc.). The purpose of the warranty is to ensure "that the equipment performs as intended by the manufacturer... when installed in accordance with the recommendations of the manufacturer."(4) The contractor should be responsible for repairing or replacing in-kind any hardware that fails to perform as indicated above during the guarantee period. The warranty does not include normal maintenance. In Federal-aid projects, any guarantee period exceeding 6 months following project acceptance must be a separate pay item, and will be nonparticipating.

Project Schedule

The specifications should require the contractor to prepare and submit a project schedule which clearly shows the sequence, time involved, and dependency of all construction activities. Schedule requirements to be addressed include:

- Format (CPM, bar chart, etc.).
- Milestones to be included in schedule (e.g., submittals; agency review; equipment delivery, installation, and completion of major components; testing; system turn-on; acceptance; etc.).
- Overall time constraints (length of project).
- Initial submission of schedule and review by the agency; the right of the agency to require modifications to any portion of the schedule judged to be impractical or unreasonable.
- Updating schedule on a periodic basis (e.g., once a month) throughout the project.

It is the contractor's responsibility (and authority) to determine the sequence and time estimates for the project. Nevertheless, it may be desirable to stipulate the sequence of some activities. For example, the problems of loop maintenance and inoperable loops at the time of system acceptance might be minimized by specifying that the loops shall not be installed until "X" number of days into the contract. The installation of highly visible components (e.g., variable message signs) might also be similarly deferred. If such sequencing and staged implementation is desired, it must be included in the specifications so that prospective contractors may obtain quotes from vendors and prepare their bids to reflect future purchases and inflation.

It is emphasized that great care must be taken when calendar days for individual milestones are stipulated in the specifications. Any specified dates must be practical -- for example, it is unrealistic to require delivery/installation of a component a short time after the submittal of the corresponding catalog cuts. It must also be recognized that the more milestone dates which are specified, the less authority and flexibility the contractor has for controlling and managing the project and fulfilling the specified responbilities.

Coordination

The specifications should include requirements and procedures for the contractor to coordinate the construction activities with utilities and other agencies. This may include requirements for the contractor to obtain the appropriate clearances from the utilities, to have on-site presence of utility representatives, and to provide an advance notice (of a specified length) prior to the participation by these various entities. Other involved agencies may include police and signal maintenance personnel. Whatever the requirement, it is important that the specifications do not conflict with the existing rules and regulations of the affected agencies.

When separate contracts for contiguous work are awarded, as they are with the systems management approach, each contract should briefly describe the other contracts and their scopes. The contractor should be required to afford the other contractors reasonable opportunity to execute their work, and be required to connect work with the work of others.

Project Management Requirements

The specifications should define key project management procedures, including:

- Channels for official communications, and how they are to be transmitted.
- Required number of copies of contractor submittals and where (or to whom) they are to be delivered.
- Time requirements and sequence of the submittals (e.g., a specified number of days after notice-to-proceed or some other milestone).
- Length of agency reviews (i.e., turnaround time).
- Resubmittal process in the event a previous submittal is not approved.
- Project management meetings, including the frequency (e.g., biweekly, monthly) and required attendees (contractor superintendent, engineer, owner's representative, etc.).

Subcontracts

As previously discussed, a prime contractor typically utilizes many subcontractors, and some of these may perform work that is crucial to the system's success (e.g., system firm which has subcontracted to an electrical prime for developing the software on a turn-key system project). While nothing in the contract documents should create any contractual relationship between the agency and a subcontractor --the prime contractor accepts full responsibility for the acts or omissions of his/her subcontractors -- some degree of agency control over the subcontractors is very important. Subcontractors should be required to comply with the principal terms of the contract and to be licensed in the State where the work is being executed. The specifications should prevent the prime contractor from awarding any subcontract until the agency has determined the qualifications of the proposed subcontractors. Similarly, the agency should have the specified authority to accept or reject any proposed subcontractor. In this regard it is important that the specifications address any qualifications and experience which specialty subcontractors are required to possess.

Contingencies

In spite of carefully prepared plans and specifications, it is fairly certain that during construction the work originally specified will have to be modified, conditions as shown on the plans will have changed, the final quantities will be different from the estimated quantities, an item or location must be dropped for successful completion of the system, or unforeseen delays and problems will occur. Additionally, it must be recognized that no design will ever be perfect. Many problems and even litigation can be avoided by addressing contingencies in the specifications. These are discussed below.

Changes in Work (Quantities)

The specifications should permit the engineer to change (increase or decrease) the estimated quantities or to delete entire items of work specified in the contract documents without constituting any grounds for a contractor claim for damages. The change order process should also be specified.

There are certain economies-of-scale in construction work and in the procurement of hardware. For example, the unit cost associated with the purchase of 100 controllers is typically less than the unit cost for one. Most specifications therefore entitle the agency and contractor to renegotiate a unit price if the actual quantities for an item vary from the estimated quantities by more than some stipulated percentage. The same threshold usually applies to all items in the contract. Traffic control systems, particularly custom and experimental applications, often involve developmental items (e.g., sophisticated communications interface). The development costs, which can be relatively large, are independent of the number of units built and installed. Thus, even a small change in the quantities can have a significant impact on the unit costs. Accordingly, consideration should be given to specifying a lower threshold percentage for such items, or otherwise providing for equitable compensation for development costs.

Extra Work

The specifications should define the procedures for accomplishing extra work -- that is, work which is not set forth in the contract documents and for which no bid price has been given. The following considerations should be addressed:

- Notification to the engineer by the contractor that work is beyond the scope of the contract documents (e.g., written notification within a stipulated number of days following issuance of change order or a notice to perform the work).
- Authority of engineer to require the contractor to proceed with the work.
- Method of compensation for the extra work (e.g., negotiated unit price, lump sum, time and materials, etc.); type of expense records to be maintained by the contractor in connection with the extra work; final determination and approval of costs of extra work.
- Procedures by which the contractor can protest against any instruction or ruling made by the engineer, and file a claim for additional compensation at the end of the project.

Extensions of Time

The specifications should address the procedures by which the contractor is to request an extension of time, and should clearly stipulate all the circumstances under which an extension of time will be granted. Excusable delays might include:

- Change orders issued for additional work.
- Extra work.
- Strikes and labor disputes.
- Abnormal violence of the elements; these should be specifically defined (lightning, tornado, etc.), not just described as "acts of God".
- Delays beyond the control, fault, or negligence of the contractor.

Given the complexity of traffic control systems and the process by which they are implemented, the last circumstance can occur frequently. There may be a problem with one of the subsystem contracts which delays the system manager's performance. Certain system components are available from a limited number of vendors, and additional time may be necessary if the contractor is cut off from his/her source of supply. Additionally, hardware and software elements which advance the state of the art often require more development time than initially anticipated.

Suspension of Work

Work stoppages are to be avoided. Nevertheless, unanticipated events do happen. For example, in one jurisdiction it was necessary to suspend a system expansion project because the initial system implementation job was still in progress, and the system was not yet operational. The specifications should therefore provide for temporary suspension of work under stipulated terms (e.g., notification of suspension, contractor compensation during suspension, maximum length, resumption of work) instead of contract breach.

Standard Specifications

Traffic control system projects are typically constructed and controlled in accordance with the jurisdiction's specifications (e.g., State standard specifications). Specifications for materials and hardware items are also available from various technical societies, government agencies, and trade associations (e.g., NEMA). These standard specifications can save contract preparation time. It is imperative, however, that the designer never incorporate any standard specification without fully examining and understanding its technical and procedural provisions. Blindly force-fitting a sophisticated traffic control system project into a standard specification that was developed primarily for other purposes (e.g., roadway and bridge construction) is bound to cause problems and confusion during the implementation phase.

The designer must make sure that the standard specifications are applicable to the project and are in agreement with the other contract documents. Any system elements which are not addressed by the standard specifications --and there are usually many (e.g., central control equipment, displays, software, communications units, communications cable, acceptance testing, training, and documentation) -- need to be included in the special provisions. Additionally, any provision in the standard specifications which conflicts with the system requirements and process must be modified by the special provisions. For example, conduit requirements contained in standard specifications often permit up to 360° of conduit bends between pull boxes. While this may be suitable for standard traffic signal cable, it makes the pulling of some communications cables (e.g., coax) very difficult if not impossible.

When published standard specifications are referred to in the special provisions, it must be made clear that the latest edition is referred to, and that the standard specifications are as applicable as if they have been repeated in full. An order of precedence among the various contract documents must also be defined in the case of conflict -- for example, the special provisions take precedence over the standard specifications which take precedence over plans, etc. The use of more than one standard specification to describe the same component can be particularly troublesome. Even if there is not a conflict in the specified requirements, it may be impossible to meet the different sets of standards simultaneously.

The specifications must also be integrated and correlated with the plans to avoid conflicts in requirements. A good rule to follow is to state in the specifications those instructions which can be better described in words, and to place in the plans all the information that can be shown most clearly by drawing. No instruction should be included in both. The specifications and the plans are legally interdependent and must be complementary.

Definite and Certain

Perhaps the most pervasive problem encountered during system implementation involves the interpretation of the specifications. Numerous examples exist where different interpretations on the part of the owner, engineer, and contractor have become controversial and costly; and in a few instances have ended in litigation.

There is no such thing as the "intent" of the specifications. The specifications either state a requirement, or they don't. On the other hand, owners do have intentions of what functions and features their system should provide, and it is the responsibility of the designer to clearly and precisely reflect this intent in the ultimate written form. Designers should never assume that others will know what is meant.

Definitiveness and certainty in the specifications are of economic value. As previously noted, contractors base their bids and cost proposals on the information contained in the specifications and plans. If the contract documents are vague and incomplete, the contractor must either gamble on these uncertainties, or increase the bid to cover the worst possible conditions. Since increasing the bid will reduce the contractor's chances of winning the job -- a situation which is contradictory to their profit objective -- most contractors will gamble and assume the minimum interpretation. Should worst-case situations and unfavorable (i.e., different) interpretations arise during construction (and they almost always do to some extent) the profit margin will disappear. The contractor may then attempt to recoup the losses through change orders, claims, and even substandard work (i.e., "cutting corners") in some instances.

An ambiguous specification is really worse than no specification at all. The designer must know what the system features and requirements are; make a thorough analysis of the function, material, or process to be specified; and then write about it with such clarity and precision that potential differences in interpretation are minimized. In other words, say what you mean, and mean what you say.

The content and detail of the specifications is a function of the procurement method. The specifications may be prepared in one of the following three basic styles:

- Sole-source, or standard brand.
- Material and methods, or comprehensive.
- Functional, or performance.

Sole-Source

The sole-source specification simply calls for the end product by the manufacturers name, or directly uses the manufacturers specification. It is often used to procure an off-the-shelf system or to expand a proprietary system. As previously discussed, the sole-source specification may violate local, State, and Federal laws regarding competitive procurement.

Sole-source specifications are sometimes used within a larger contract to specify a particular system component -- for example, a software specification which requires UTCS. The "or equal" clause is often used in these circumstances as a legal means to permit free and open competition. However, a determination of what is "equal" can be a problem, and the use of this clause is discouraged. If the "or equal" clause is incorporated into a specification, it should be supplemented by a quality and performance specification as a guide in selecting the equivalent; or a list of equivalent materials/components may be added. Another alternative, when using a two-step process, is to require a statement in the technical proposal of any substitutions from the named product the contractor intends to use. The burden is then on the contractor to prove that the substitute is equal.

Materials and Methods

In a materials and methods specification, the designer describes in detail the materials needed, the features to be incorporated, and the method of putting the various units together to obtain the desired system or subsystem. This type of specification is typically used with the system management process. The system manager -- who is the designer and the responsible entity --tells the various contractors how to manufacture and install the system elements so that they can be properly integrated (by the system manager) into a fully operational system.

With a materials specification, the contractor is responsible only for constructing the system or subsystem in accordance with the requirements of the specification. The contractor can not be expected to guarantee the suitability of the finished product. As such, a materials specification transfers the responsibility for acceptable functional performance from the contractor to the system designer.

Functional

A functional specification defines only the operation and important characteristics of the final product. They describe what the completed system should do. Determination of the materials and methods to be used in achieving the specified performance is the responsibility of the contractor. The contractor must also guarantee the suitability of the finished system.

Functional specifications must be flexible. Whenever alternative techniques for accomplishing the same end result are available, the contractor should be given the freedom of selecting the best approach, subject to local constraints and approval of the contracting agency. Functional specifications are best suited for the engineer-contractor approach. The contractor, who is the responsible entity, is provided with the necessary flexibility and authority to control and manage the risks associated with the project, and to deliver a system which satisfies the specified performance requirements.

Discussion

A major dichotomy of system design is that the flexibility offered by a functional specification also allows for ambiguities which, in turn, can lead to serious disagreements in interpretation. To avoid this problem, many designers have decided that a particular section (or sections) of a performance specification should also include details concerning materials and methods. In doing this, the designer must realize that he/she assumes responsibility for the completeness and accuracy of the material/method specifications and plans, that ambiguities regarding system responsibility have been created, and that the accountability of the contractor may be diminished.

Combining material and functional requirements can prove disastrous if the two are in conflict. For example, consider a contract document that describes in detail the manner in which the work is to be done and the materials to be used in constructing a building. The specifications also require the contractor to make the basement watertight. The contractor uses the materials called for in the specifications and applies them in the manner prescribed, but the basement floods (i.e., not waterproof). The owner refuses to make final payment on the contract and, as a result, the contractor brings legal action to recover. The contractor's position is that all that was contracted to be done was, in fact, done -- furnishing the materials of the quality required and applying them in the manner prescribed. On the other hand, the owner claims that the contractor had promised to furnish a waterproof cellar. Who is right?

The above example is a summary of the case "MacKnight Flintic Stone Co. vs Mayor, Aldermen and Commonality of City of New York, 160 N.Y. 73, 54 N.E. 661-1899".(5) The contractor either promised to follow detailed specifications, or promised to provide a waterproof basement. The promises were in conflict since it was obviously impossible to follow the contract documents <u>and</u> provide a waterproof basement. The court concluded that the parties had intended the contractor to follow the plans and specifications. If the plans and specifications, when fully performed, would not provide a waterproof basement, the fault was with the City and not the contractor.

If full compliance with the detailed <u>material</u> requirements of a contract document does not satisfy the <u>functional</u> requirement of "furnishing and installing a fully operational traffic control system", then problems and procedural failures will certainly occur. When such a conflict exists, it is generally held that the more specific requirements (material and methods) control the general (functional). The agency (i.e., designer) will likely be held accountable for any problems, and the contractor may be entitled to additional compensation for extra work performed as a result of the defective designs.

Given the complexity and technology of traffic control systems and the potential for widely different interpretations, it is unrealistic nor desirable to merely specify the end result desired, and leave all the methods and material decisions to the discretion of the contractor. For example, a technically obsolete item of equipment may satisfy the functional requirements, but become a costly maintenance item for the agency. Constraints of a material and method nature are therefore essential for a systems project. However, when incorporating these details into a functional specification, the designer must be aware of the potential problems previously discussed and be cognizant of the following guidelines:

- If required to follow detailed specifications and plans furnished by others, the contractor does not guarantee their sufficiency.

- When the specification is detailed, the statement of desired results and performance will not make the contractor a guarantor of the finished product, nor will it change the material specification to a performance type. (Nevertheless the clause indicating the desired result is useful in the cases of ambiguity or vagueness requiring interpretation of the contract.)

- The designer is responsible for the consequences of defects in plans and specifications. This responsibility is not overcome by the usual clauses requiring contractors to visit the site, to check the plans, and to inform themselves of the requirements of the work.

- Material specifications should never control the management responsibilities of the contractor (e.g., including a detailed schedule in the specifications).

Specification Preparation

Regardless of the type of specifications used in a project, their effectiveness is, to a large degree, a function of the quality of writing. Table 6 summarizes attributes of well-written specifications. Table 7 lists terms which are frequently misused in specifications.

The importance of definitive, well-written specifications cannot be underestimated. The following case studies provide interesting examples of how the written word can be interpreted and even manipulated by a contractor to his/her advantage.

Case Study Example #1

Sections of a software specification for a system project are reproduced in table 8. The contractor, in his software description submission, stated that the system would provide the traffic operations capability for a functional 1 GC system utilizing UTCS as defined in the referenced documents. Since FHWA-UTCS was to be utilized, the specified software fell into three categories:

> "1 - capabilities included implicity in UTCS, and therefore would be supplied by the Contractor (Items a, b).
>
> 2 - capabilities not included in UTCS, but which were specified to be supplied by the Contractor (Items c, d).

Table 6. Attributes of well-written specifications.

- Specifications are mandatory and legal in character, and must therefore be precise in wording and punctuation. Specifications should utilize short, concise sentences in the simplest style possible. Hyphens, commas, and semicolons should be used sparingly. The entire meaning of a sentence can be changed through the omission of a punctuation mark.

- Follow elementary rules of grammar. Avoid expressing more than one thought or instruction in a sentence. Nouns should be repeated rather than using pronouns to ensure that the meaning is clear. This may lead to a choppy and boring writing style but the elimination of errors and ambiguities is worth it.

- The specifications should use words of common or general acceptance instead of colloquial phrases or terms. Any technical terminology should be commonly used in the traffic control system industry. Words which may be unfamiliar to the contractor and words with more than one meaning should be defined, or avoided altogether. Don't seek out synonyms for literary effect.

- The specifications should be organized in a consistent format which is systematic and logical. The format, style of writing, and verb tense should be consistent throughout. When modifying a set of standard specifications, use the same format.

- All instructions must be written in the form of specific directions; never as suggestions or explanations.

- The scope of the subject matter should be confined to the information and directions necessary for the material or construction activity. No additional information outside the scope should be included.

- Completeness should not be confused with level of detail. A complete specification is one that thoroughly describes all elements (functional or material depending on the procurement approach) of the equipment being specified, all of the conditions under which these elements are required, and every contractor activity. Don't assume an unspecified element because of it's "apparent" dependency on another.

- The level of detail associated with the specification of a particular item should be consistent with the importance of that item. The level of detail should also be consistent with the extent of the anticipated inspection process.

- The purpose of specifications is to amplify, not repeat, information shown on the plans. The plans show how the components are to be incorporated into the system. The specifications state the quality of the materials and the workmanship to be employed on the project.

Table 7. Terms that are often used incorrectly in specifications.[9]

Terms	Preferred Term	Comment	Example
Any, All	All	All is the more definite of the two terms.	"The contractor shall perform any work required" should read "The contractor shall perform all work required."
Either, Both	Both	Either implies a choice.	"Barricades shall be placed on either side of the roadway" should read "Barricades shall be placed on both sides of the roadway."
And, Or	--	Care must be taken to select the proper term. And is an inclusive term that implies both; or connotes either.	"The detector installation shall be free from electronic defects and weak cable" has a completely different meaning than "The detector installation shall be free from electronic defects or weak cable."
Must, Shall	--	Select one and use it consistently throughout.	
Will, Shall/ Must	As Noted	Use "will" for acts of the owner; "shall/must" for acts of the contractor.	The State will provide data. The Contractor shall develop the data base.
Amount, Quantity	As Noted	Use amount for money; quantity for other items.	The quantity of mast arms is 30. The amount of their cost is unknown.

3 - capabilities needed for system operation, but which are not included in UTCS nor specified to be supplied by the Contractor, and accordingly would not be furnished by the Contractor under the existing contract (Items f, g, h)."

To say the least, the contractors interpretation came as a major surprise to the agency and their consultants. Their "intent" was to have the contractor supply all of the capabilities listed in section 2. The contractor was requested to explain his interpretation of the software specification in writing. Key excerpts of the contractor's interpretation are noted below:

- Section 1 - Contractor has option of providing either UTCS suitably modified to operate on the computer hardware to be supplied, or another existing operational software package of equivalent capability.

- Section 2 - Paragraphs A through H are provided to "assist" the contractor in identifying the tasks required for implementation of the traffic control package only if he chooses to deliver a system by modification of an existing non-UTCS package. If UTCS is used, then:

  - Where functions are provided by UTCS, they should be provided as specified in the UTCS documents. Modifications shall be permitted only to the extent that they do not destroy the "similarity" to UTCS.

  - The Special Features required by the specifications, namely Fire Preempt Software and Speed Control Signs, will be provided as add-on software packages and made to run with the UTCS program. Please note that for these items (C, D) the specification clearly states that "the Contractor shall provide" or "shall be provided by the Contractor".

  - The specification is vague regarding the responsibility for the other add-on software packages. The contractor interprets these add-ons as not a contractual requirement.

In essence, the contractor took a very narrow interpretation. That the system be similar in operation to UTCS was the paramount objective. According to the contractor, it was a technical impossibility to furnish all the details of Section 2 <u>and</u> still deliver an operational system similar to that in operation in UTCS. Any add-ons in Section 2 were not their responsibility unless specifically stated. It is noted that the contractor obviously based his bid on this interpretation. The bid price for software was $100,000 to $220,000 less than the other bidders, and this difference was paramount to submitting the low bid.

Table 8. **Software specifications, case study example #1.**

Section 1. General

The Contractor shall supply, install, and make operational in the System a traffic control software package that shall provide all of the traffic operations capabilities necessary for a fully integrated and completely functional first-generation traffic control system as defined by the Federal Highway Administration. This traffic control system shall be derived by suitable modification of the Urban Traffic Control System (UTCS) software package or with the approval of the agency, may be derived by modification of an existing operational software package of equivalent capability.

Section 2. Specific Performance Requirements

Some of the specific performance requirements in the software package are listed below to assist the Contractor in identifying the tasks required for implementation of the traffic control package to be supplied. Enumeration of these functions is not intended to relieve the Contractor of the need for delivering a completely integrated operational system, similar to that in operation in UTCS.

a. Controller Monitoring - The traffic control software shall provide the logic necessary to monitor individual controllers . . .

b. Map Drive Software - Control of the display map shall be exercised by software so as to provide the information required in the map display . . .

c. Speed Control Signs - The Contractor shall provide the software necessary to properly communicate with and control the speed control signs . . .

d. Fire Preempt Software - All of the software necessary to support the operation of the fire preempt panel shall be provided by the Contractor along with reports . . .

e. Transfer to Back-Up Panel - The software necessary to relinquish control of the signal system to the back-up panel during the execution of a commanded orderly termination of computer control shall be provided . . .

f. School Related and Miscellaneous Blankout Signs - Blankout sign control is required at intersections . . .

g. Subsystem Configuration - It shall be possible for any given intersection to be assigned to different subsystems in different traffic patterns without requiring operation intervention . . .

h. Maximum Configuration to be Supported - The control software shall be sufficient to control the ultimate complement of 300 intersections and to accommodate the ultimate complement of 750 system detectors up to these limits . . .

As noted, the agency vehemently disagreed with the Contractor. The agency's interpretation was that there were no "category 3" items and that the Contractor was required to provide all the features delineated in Section 2 unless specifically designated to be provided by others, not just those preceded by the phrase "the Contractor shall provide". The Contractor, in their opinion, had taken the word "assist" out of context.

After several meetings and letters the issue was still unresolved. The agency wrote the Contractor that the specifications provide that the "engineer shall have final authority in all matters concerning interpretation of the contract". The Contractor was directed to proceed with the work in accordance with the agency's interpretation. If the contractor still "did not agree with this interpretation, they should notify the agency of their intent to file a claim (in accordance with the provisions of the specifications) and proceed with the work"; which the Contractor did. The claim was never filed in return for the elimination of liquidated damages. So, in a way, the Contractor won the battle. The example may be extreme, but it shows the importance of carefully prepared and explicit specifications. State exactly what you mean, and avoid conflicts.

Case Study Example #2

The format and structure of the specifications is also very important. For example, the first paragraph of a section in a software specification stated that:

> "The traffic control system shall provide conversational software in the form of simple English language which shall enable the traffic control system operational staff to input parameters and data, and to output reports and data related to the operation and performance analysis of the system." . . .
>
> Four paragraphs later, the specification stated that:
>
> "The software shall also provide the capability for the operator to have complete control of all parameters, constants, and functions which exist in the software."

During a factory software demonstration test, the agency identified a "major deficiency" -- not all parameters and functions were accessible via the English language conversational mode. Some parameters could only be modified off-line, or required knowledge of hexadecimal. Even though the word "all" was not included in the first paragraph, the agency's interpretation was that since both paragraphs were under the same section, they were dependent on one another.

Not surprisingly, the Contractor's position was different. It was the Contractor's view that the two paragraphs were independent, and that their "marriage" and the agency's corresponding interpretation was not possible for the following reasons:

- The words in the first paragraph do not say that the operational staff is to input <u>all</u> parameters and data in a conversational mode.
- The words in the first paragraph do not say specifically what parameters and data are to be entered in a conversational mode.
- The first paragraph is not a major heading paragraph with the subsequent paragraphs as subheadings. In other instances in the Specification when a paragraph is to be a major heading, the specification clearly denotes this by subnumbering the subsequent paragraphs.
- The paragraphs in this section are separate paragraphs dealing with separate subjects. Indeed, some of the paragraphs discuss considerations other than operator inputs or operator requested outputs.

The matter was never resolved and ended in a claim situation. Which interpretation was right (or wrong) is not important. The key point is that a lot of time, trouble, and costs could have been avoided if the specification had clearly stated the desired result.

Testing and Acceptance

The purpose of conducting acceptance testing is to demonstrate the proper operation of the system and its components. The testing and acceptance provisions are therefore some of the most important aspects of the system specifications. Furthermore, successful completion of acceptance testing provides a formal recognition that the contractor has completed the work in accordance with the contract documents. They provide the contractual means by which the owner may enforce quality control of the contractor's efforts.

Test Requirements

Acceptance test requirements should be determined during the traffic engineering analysis (refer to chapter 3) and explicitly described in the specifications. There are four basic categories of acceptance tests:

- Materials acceptance - review of catalog cuts and shop drawings. The specifications should state, however, that acceptance of these submissions will not constitute a waiver of any contractor responsibilities.
- Preinstallation tests - factory acceptance and environmental tests, certifications from independent testing laboratories, or user-performed tests.
- Component tests - after installation, system components should be tested on an individual basis to verify proper operation.
- System acceptance test - the integrated system must be tested to determine the total system's reliability and performance under actual traffic conditions over a period of time (e.g., 2 weeks to 1 month).

While it would be preferable to test every system component at every step of the installation phase, the designer must recognize that testing can be very expensive, and such an extensive level of testing may not be economically feasible. The designer must ultimately decide which tests are necessary for each system element, what level of testing is cost effective, and how the tests will be conducted and evaluated. At the very minimum, every component and subsystem should be tested at least once during the installation phase.

The extent and level of testing for a particular component or subsystem should correspond to that component's/subsystem's complexity, it's failure potential (which is often a function of it's complexity), the consequences should the component or subsystem actually fail, and the effort required (i.e., labor, equipment, time, cost) to correct a failure. The communications cable network and system software are prime examples of system elements which typically require extensive testing. Cable networks often have a high failure potential, and a disruption in communications can render the entire system inoperable. Real-time software is very complex, with literally millions of different calculations and decisions possible. Accordingly, the potential for software problems ("bugs") is quite great. It is important that these bugs

-- and there always are some -- be discovered and corrected during the start-up period. If a software problem is not discovered until after system acceptance, its correction may prove troublesome.

Identical components may require more extensive testing in one system than in another, depending on their intended function. For example, system detectors are more crucial to the successful operation of a freeway surveillance system (for real-time incident detection and flow measurements) as compared to a traffic signal system (which can revert to time-of-day operation with minimal impact). Accordingly, system detector testing is usually more extensive in freeway system projects.

The methods and procedures for testing a particular component should reflect the manner in which the component has been specified. As previously discussed, a functional (i.e., performance) specification describes the important characteristics of the end product. Accordingly, the testing procedures should focus on this end product, and assure that the final subsystem or system possesses the required features and functions and meets the specified standards of performance. If a material specification is used to describe a component, then the testing method should verify that the various materials satisfy the specified requirements and have been installed properly. In essence, testing should reflect the desired results as described in the specifications.

If a particular component or subsystem is to undergo testing, then <u>all</u> of its specified features and capabilities should be tested. If the requirement is worthy of being included in the technical specifications, then it is also worthy of being tested. For example, the software and central computer hardware are often specified to be "capable of controlling X-number of signalized intersections (or ramp meters) with Y-number of system detectors, and perform all of the specified functions," and that "expansion of the system to the ultimate size shall only require extension of the cable network, the installation of communication units, and addition of data base". The initial size of a system is usually much less than the specified capacity. The system should therefore be tested at full capacity (simulated) to assure that it will function properly when fully loaded and can be expanded as specified. Otherwise, future expansion projects may run into major difficulties. This system expansion testing may include software benchmark testing; and/or the installation and integration of hardware (signal, ramp meter) by the user and bringing these locations on-line on a random basis, thereby testing not only the expansion capabilities of the system but also the thoroughness of the training and documentation.

Another example of the need to test all specified features is a coax cable network with thermal equalization amplifiers. A single end-to-end cable test may not be sufficient, since it does not evaluate the thermal equalization capabilities. Several end-to-end tests should be conducted under various weather conditions (i.e. temperature extremes) to assure that the amplifiers properly compensate for temperature-induced changes in cable attenuation. Otherwise, the agency may find itself with an inoperable system should there be a significant rise or drop in the thermometer reading.

Testing Specifications

After the testing requirements have been determined, it is essential that they be clearly and thoroughly defined in the specifications. Under no circumstances should the phrase "to the satisfaction of the Engineer" ever be used to define the acceptance criteria for a component or subsystem. In a contractual situation, the satisfaction of the Engineer is not dependent on the arbitrary whim or caprice of the designated individual. Instead, this "test" means the satisfaction of a reasonable person. "Reasonable satisfaction" can be interpreted in many different ways, and it is not unusual for the contractor and the owner to have opposing views on this matter --the contractor stating that the item is satisfactory, while the owner declares that it is unsatisfactory. As previously noted, differences in interpretation such as this usually disrupt the system process, and can delay system implementation, require additional funding, and in some instances even result in litigation -- all of which are symptoms of a system failure.

The testing and acceptance provisions of the specifications must make it clear to all parties what exactly will constitute a satisfactory component, subsystem and system; define what will be required for acceptance; and state precisely when and under what circumstances acceptance will occur. The previous guidelines regarding completeness and certainty in specifications also apply to the preparation of the testing and acceptance provisions. Additional guidelines are discussed below.

Definitions

Define all of the tests that will be conducted. If a particular test is not specified, but is nonetheless conducted and the system fails this test, the contractor may contend that the system does satisfy the specifications; and that the issue of the system's apparent failure relates to the techniques used to conduct the testing. In other words, the contractor can claim that the basis upon which the owner determined the existence of a failure is outside the requirements of the specifications. For example, in one project the specifications required that "the contractor shall demonstrate that the hardware and software have sufficient capacity for the fully expanded system". The agency tested the system using a fully-sized data base consisting of mostly non-existent intersections. The system did not function in accordance with the software specifications, and the owner withheld system acceptance. The contractor responded that the specification did not impose the requirement of conducting tests under a simulated full system operation; that there is a significant difference between the effort required to "demonstrate" that the system sizing is proper and the effort required to simulate and debug a fully-sized operational system; that the cost and time difference between these two efforts was not reflected in the bid; and that since simulation of the fully-sized system is not required in the specifications, the identification of problems and the corresponding revisions of the system under such circumstances are considered extra work.

Standards

Objective standards must be used to measure performance and to determine if the test results are acceptable. Furthermore these criteria must be defined in the specifications. Examples include:

- Published standards (REA, NEMA, etc.).
- High and low extremes and maximum allowable rates of change for environmental tests.
- Test voltages and frequencies.
- Maximum/minimum allowable resistance and attenuation for cable testing.
- Number of days that a component/subsystem/system must function properly.

When a test requires that a system operate for a specified period of time with no or limited failures, terms such as "trouble-free", "down-time", "intermittent", and "failure" should be clearly defined. It may be beneficial to identify and list in the specifications reason for terminating and/or suspending a timed performance test. An example of these criteria is provided in table 9.

Testing Process and Responsibilities

The testing process and testing responsibilities must be fully described. For example, the testing specifications must specify:

- Who conducts the test.
- What test equipment is necessary, and who furnishes this equipment.
- Who documents the test results.
- Who may witness the tests.
- What is the process for reviewing and accepting the test results.
- Do all components get tested, or just a sample; what is the sample rate.
- When may acceptance testing commence (i.e., submittals, work, and other tests that must be completed prior to the start of a specific test); the sequence of the various tests.
- How are tests paid for -- separate bid item or incidental to the cost of the component being tested.

The specifications must also thoroughly describe the process in the event a test is not passed, for example:

- Notification to the contractor in writing, within a specified time period, stating the reason for the failure.
- Replacement or repair of defective components within a specified time period, at contractor's expense.
- Retest procedures -- when the retest may commence; the functions and aspects of the component/subsystem to be retested (i.e., repeat the entire test, or just the elements that failed).

Table 9. Reasons for suspending or terminating 10-day performance test. (Source: Columbus, Ohio)

SUSPEND

- Failure or interference due to conditions beyond the control of the Contractor, such as vandalism, traffic accidents, power failures, lightning and similar occurrences.
- Failure of any support or diagnostic equipment necessary to successfully test the system.
- Failure of any line amplifier.
- Failure of non-critical central equipment, such as line printers, maps, graphics displays.
- The failure of more than one intersection (or 5%, whichever is greater) in any 2 day period.

TERMINATE

- Failure of any hardware, software or performance item to meet the operational requirements of these specifications.
- The failure of more than one intersections (or 5%, whichever is greater) in any one day, except when caused by a line amplifier failure (see suspension).
- The failure of an individual intersection more than 3 times within a 5-day period.
- A hardware failure of the computer or associated critical peripherals (i.e., hardware necessary to fully operate the system).
- A software error which causes the system to crash, causes an unsafe street condition or causes the system to become divorced from the true date, day of the week or time of day.
- The appearance of any problem which has a significant effect upon the reliability, safety or operation of the system.

Test Procedures

It may not be possible to include detailed test procedures in the specifications for those system elements which are defined in functional terms. In these circumstances, the specifications may require the contractor "to develop test procedures (e.g., factory acceptance tests, software test) which cover all operational and technical aspects of the equipment and demonstrate that all specified performance requirements are satisfied". It is usual practice to also include the requirement that the test plan is subject to the "review of the engineer, who will either accept or indicate changes that are required for acceptance".

When such provisions are included in the specifications, it is essential that guidelines also be provided for the development and submittal of the test plans. These test plan guidelines should follow the same basic rules previously discussed for the preparation of test specifications, including:

- Stating what components are to be tested; and if all units or just a sample will be tested.
- Defining the type of tests to be included in the plan (e.g., industry standards, manufacturer diagnostics, environmental conditions, electrical and material, functional tests in a simulated environment and/or under actual operating conditions, etc.).
- Stating the minimum duration of the tests as may be appropriate.
- Addressing key elements of the submittal and testing process (e.g., time permitted for the engineer to review test plan submission, who conducts the tests, witnessing, documenting test results, retests, etc.).

Simply stating that the contractor's test plan is subject to the review and approval of the engineer may lead to major differences in interpretation and significant problems in determining what constitutes a "reasonable" test plan.

Training and Documentation

Provisions addressing system training and documentation are important elements of the system specifications. These are discussed in chapter 6 on system operations and maintenance.

Economically Sound

The functions, materials, and methods required by the specifications must be adequate for the job, but they must also be economical. This includes the initial capital and installation costs, as well as a consideration for the operations, maintenance, and system expansion requirements. For example, a system component which ties the owner to a single manufacturer may hamper maintenance and system expansion should the component's manufacturer significantly increase prices or go out of business. Materials which are developmental or expensive should not be specified unless the nature of the system and the corresponding work demands them.

The designer should give serious thought to specifying standard components or processes for the system. However, the designer must also be satisfied that the standard products are adequate for the intended use. Similarly, where alternative methods of testing are available and equally reliable, the least expensive method should be chosen.

Fair and Just

The specifications must be fair to all involved parties, with risks equitably distributed. An unfair specification may reduce the number of potential bidders. A harsh specification may prove unworkable and necessitate changes from the exact wording of the contract. This means that the project engineer will have to make decisions regarding variance and exceptions to the contract documents. Questions of authority for making these variations and the extent of the exceptions will enter into the system process, and provide potential sources of friction and misunderstanding between the involved parties -- the owner, engineer, inspectors, and contractor. A general rule to follow is to never put anything in the specifications you do not expect to, or cannot enforce, to the letter.

PLANS

The plans provide <u>all</u> of the construction and technical details, and are the basis for estimating costs and contract bidding. In general, a set of plans will contain the following:

- Title sheet.
- Summary of quantities.
- General notes (pertaining to entire scope of project).
- Location plans (each intersection or ramp control location).
- Communications and conduit runs (map and/or table).
- Signal phasing charts.
- Control center.
- Standard detail sheets.
- Revisions and plan changes.

Many of the guidelines for successful specifications are also applicable to the development of plans. The plans must be correct and complete, concise and definite, and economic. If the plans furnished by the designer are technically incapable of producing the desired results, or if they lack or misrepresent essential information and conditions, then the contractor will likely be entitled to extra compensation or even excused from performance.

Existing Facilities

Incorporating existing facilities -- whether they be conduit, controllers, or communications cable -- into a traffic control system can save significant sums of money. However, if the existing facilities are not suitable for the intended purpose, then their inclusion in the design may end up costing more than if new facilities had originally been provided. The contractor does not guarantee the sufficiency of the plans. It is the designer who is responsible for ensuring that the information shown on the plans is accurate and suitable for the intended purpose; and this responsibility cannot be obviated by clauses requiring the contractor to examine the site and satisfy himself as to the existing conditions and arrangements. Accordingly, it is imperative that during the planning phase or at the beginning of the design phase, any existing facilities which may be used in the system be identified, located and field checked, thoroughly reviewed, and in some cases tested. For example:

- Compatibility of existing controllers with the specified control scheme.
- Available space within existing cabinets for the addition of system components (e.g., termination panels, detectors, communication units, etc.).
- Verification of the existence of conduit runs as shown on "as-builts". Existing conduit should be physically rodded to ascertain if there are any breaks or collapsed sections. If a problem is identified, then the design should be modified to avoid using these facilities, or to include contract items for their repair or replacement.
- Suitability of existing conduit. Possible problems include insufficient space (i.e., usable area filed by existing cables); too many bends between pull boxes for the proposed cable type; radii of conduit bends are too small for the proposed cable; distance between pull boxes too great; pull boxes size/construction inadequate for cable splices, pulling cable, or cable loops.
- Suitability of existing communications cable to handle the proposed communications mode and scheme.

A general rule-of-thumb regarding existing facilities is that if any doubt exists about their suitability, they should be replaced as part of the system project. If not, at least provide contingency provisions in the specifications and in the project budget. Simply assuming that existing facilities are adequate for the intended purpose will, more often than not, come back to haunt the designer and the entire system process.

Underground utilities pose a special problem. The installation of new conduits and/or foundations usually means that conflicts with existing utilities will result. The exact locations and depths of underground utilities is seldom known with any sort of accuracy. Some are usually found in unexpected locations, and their presence may require that conduit be rerouted or a foundation relocated. There is no absolute solution to the potential problem of underground facilities. It is therefore best to document existing conditions as accurately and thoroughly as possible, include provisions requiring the contractor to contact all utilities before any digging is to occur, and also to accept the fact that unforeseen situations will arise and to provide contingencies.

Notes

Notes on the design plans constitute a form of specification in that they provide information that cannot be communicated by the drawing alone. The prime requirement in the preparation of the notes is that they be clear, concise, specific, complete, and as carefully worded as if they were to appear in the specifications. Being a form of specification, the question may arise as to whether the note information should also appear in the printed specifications. It is best to avoid duplication wherever possible so that if changes are made, only one document needs to be revised. With duplication, there is the risk that the revisions will not be incorporated on all the necessary documents, resulting in contradictory information when the contract goes out for bid.

In general, if certain instructions relate directly to what the plan drawings portray, and particularly if these instructions apply to only one drawing, then the instructions should be placed in the form of notes on that particular drawing. For instructions that are common to a number of drawings, it is advisable to include the information in the specifications where it can be made to apply to all affected drawings. One practical consideration to keep in mind is that field or maintenance personnel ordinarily work from project plans and may not have ready access to the specifications. Consequently, it can be argued that this information should be repeated in a set of general notes to the plan set for the convenience of the field workers. If so, then diligence is required when revising the contract documents.

QUANTITIES AND ESTIMATES

Cost estimates can be used for a variety of purposes, including estimating the total cost of the project, evaluating the contractor's proposals, and negotiating changes in the contract amount based on variations in estimated quantities. There are two types of contracts, each requiring a different type of cost estimate:

- Lump sum - a single price for all work.
- Unit price - based on actual quantities of materials supplied and work performed for each item of work. There is a separate unit price for each item.

Construction contracts for signal systems are typically of the unit price type. However, since the estimate of quantities is usually not exact at the time the contract is executed, provisions are made for payment to the contractor on the basis of actual quantities used at the unit prices specified by the contractor in his bid. For the purpose of comparing bids, an appropriate total cost is determined from the estimated quantities and the unit prices in the bid. This approximate total cost is considered as a lump-sum in the determination of the low bidder.

When a project overruns the budget, it is very possible that the cost estimate is the cause of the "failure"; not the contractor nor the construction manager. Thus, the key element of a "successful" cost estimate is accuracy, for both the quantities and the unit prices.

Most quantities can be obtained from the system plans and specifications. While this is not difficult, care and diligence are necessary to ensure that all the required pay items are included, and that the corresponding quantities are estimated accurately. If the quantities are incorrect and prospective contractors notice the error, an unbalanced bid may occur -- the contractors placing a high unit price on small, underestimated quantities in hopes that a change order for an increase in these quantities will yield increased profits.

The quantity estimate must be developed by the designer from the best information available at the time the system is designed. Variation from these quantities can be expected, but problems can arise when the actual quantities are radically different from those estimated. In these instances, the contractor may request and be entitled to a change in the unit price.

Accuracy in quantity estimates is particularly important for developmental items (e.g., communication units). A vendor's quote to a contractor will be based on building and supplying the estimated number of units. If the quantity is radically reduced, the vendor will have to spread the development costs over a smaller number of units resulting in a higher unit price. In some instances, the vendor's quote may have been conditioned on the estimated quantity; and if the number of units is significantly reduced early in the project, the vendor may simply refuse to build the component at all. This will force the prime contractor to find another vendor, and may cause a cost increase and delays.

Another important consideration is consistency. The optimum situation is to show the estimated quantities in only one place -- the quantity sheets. The quantities should not be stated in the specifications; but if they are, it is imperative that the quantity sheets and specifications not be in conflict.

Accurate unit costs can be difficult to obtain. Not only do the costs of high-tech system components change rapidly, but the economic and market conditions are also in a constant state of flux. Unit costs can be compiled from a number of sources:

- Prior bid information. Many States compile the results of several bids from similar type projects into weighted average unit prices. Care should be taken that the current project and previous bids have a similar scope and magnitude.
- Local labor rates.
- Manufacturers equipment prices for specialty items.

Pay Items

The specifications must be concise in defining the various pay items and in describing the methods by which these items will be measured. After all, the computations for payments to the contractor depend on these pay items. The specifications should clearly state:

- Components and activities which are included in a pay item. Each system component and construction activity must be included in one, and only one, pay item. The use of broadly defined and unclassified pay items, or the inclusion of work as being "incidental" to an unrelated pay item, can cause problems if unforeseen conditions arise during construction. Having a large number of pay items does increase the possibility of arithmetic errors during bid computations and requires more construction management effort, but the additional flexibility may be worth the extra effort.
- When unit becomes eligible for payment -- delivery, installation, completion of testing, etc.
- If and when partial payment for stockpiled materials is permitted, and under what circumstances.

REVIEW

Prior to bid, the plans, specifications, and estimates should be thoroughly reviewed and scrutinized. Persons who are intimately familiar with system technology, construction management (e.g., inspectors), contract terminology, and operations and maintenance, should all be involved in this review. Furthermore, the reviewers should not have been intimately involved with the design effort. The purpose of the review is to ensure that the final contract documents:

- Contain adequate information such that the owner will be provided with the designed system.
- Provide the contractor with the required flexibility concomitant with the specified responsibilities.
- Use appropriate terminology, wording, and formatting such that the legal implications are what the designer intended.
- Contain no inconsistencies which, if followed by the contractor, would prevent the system from working.
- Describe each requirement with such clarity and precision that the chances of a major difference of opinion between the owners, engineer, and the contractor are minimized (i.e., singular interpretation).

The last review item is really a "devil's advocate" role, but it is an important one. As previously noted, interpretation is often the most significant problem during the system implementation phase. Designers and engineers must always remember that a contractor's interpretation does not have to be the same as theirs to be valid, it only must be reasonable.

5. SYSTEM INSTALLATION

The success of the system installation phase is, to a large degree, dependent on the quality of the work which preceded it. Thorough planning, coupled with complete and definitive plans and specifications, are essential to the installation of a successful traffic control system. However, no set of contract documents will ever be perfect. Some facilities, such as underground utilities, may not be shown on the plans nor marked out in the field (a consequence of erroneous or inadequate records), and their existence remains an unknown until the contractor literally runs into them. A time lag usually exists between the design phase and the actual start of construction, during which conditions as reflected in the plans or the technological state-of-the-art may have changed. Designers and contractors are only human, and mistakes are going to be made and minds changed. Finally, regardless of how definitive and certain the contract documents are, there will always be some conflicting interpretations as to their exact meaning.

Good contract management and thorough construction inspection are essential to a system's success. The biggest errors, longest delays, and the largest cost overruns have occurred during system installation. Unless this phase is properly managed, it can break a project and turn the system into an operational failure and maintenance nightmare.

CONTRACTOR SELECTION

The initial step of the system installation is to select a contractor(s) for the work. The procedures for awarding contracts are usually governed by local, State, and Federal policy, and typically involve competitive bidding.

Prequalification

The selected contractor and subcontractors must have the necessary experience and qualifications to perform the work described in the specifications and shown on the plans. Yet contractor selection is an element in which the local agency often has the least amount of control. The system project may be viewed by some potential contractors as just another signal or highway job; and failure to recognize the special skills necessary for sophisticated hardware and/or system integration can spell disaster for the system as well as possibly the contractor. Additionally, an inherent danger of the low bid process is that an inexperienced contractor may "buy" the project -- underbidding and losing money -- as a means to gain experience and credibility in the field.

These pitfalls can usually be avoided by requiring contractor prequalification. The purpose of prequalification is to establish the ability of potential bidders to perform the work. This may occur in advance of or concurrent with the normal selection process. The use of some form of prequalification process is recommended for all traffic control system projects. The depth and breadth of information required will vary with the size, complexity, and nature of the system (i.e., off-the-shelf, custom, experimental). In some instances the standard contractor surieties and bonds will be sufficient. In other systems, a two-step process may be necessary.

As previously discussed, the prime contractor typically uses multiple layers of subcontractors in constructing and implementing the system. Many of these subcontractors will perform work that is crucial to the system's success. As such, it is important to include subcontractors in the prequalification process, particularly for those who will perform software development, system integration, and other specialized activities (e.g., installing fiber optics cable). The same guidelines for determining a contractor's responsiveness should also apply to subcontractors. (Refer to the previous chapter regarding subcontractor provisions in the specifications.)

Prebid Conference

Disagreements between the contractor and agency regarding the meaning of the contract documents is a common problem during system installation. A prebid conference can be a useful first step in resolving these misunderstandings. Making attendance at the prebid conference mandatory, as a prerequisite to bidding, may even be considered in some instances.

The prebid conference should be the mechanism by which the agency/designer clarifies its interpretation of the contract documents, and states what the contractor can expect during the construction and implementation process. In essence, the prebid meeting will hopefully ensure that all contractors bid/propose on the same system and scope of work. Items that should be addressed during the prebid conference are summarized in table 10.

Table 10. Prebid conference.

- INTRODUCTIONS
- BACKGROUND OF PROJECT
- PROCEDURES OF MEETING
  - Sign-up sheet
  - Minutes/transcript to be kept
- PURPOSE OF MEETING
  - Clarify contract documents, discuss construction process, answer questions, etc.
- AGENCY ROLES (City, State, FHWA, Systems Manager, etc.)
  - Who is engineer, inspector, advisors, etc.
  - Who makes final decisions regarding submittals, interpretations, change order requests, etc.
- PREQUALIFICATION REQUIREMENTS (if any)
- CONTRACT LETTING/AWARDING
  - Events occurring before, during, and after bid opening
  - Schedule of events
- PROCEDURAL ISSUES AND REQUIREMENTS
  - Review of general conditions in specifications
  - Submittal, review, and approval processes
  - Meetings
  - Superintendent
  - Licensing
  - Subcontractors
  - Minority participation
  - Other
- REVIEW OF PROJECT SCOPE
  - Meaning and intent of contract documents (emphasis on key elements)
  - Clarification of responsibilities (e.g., maintenance, testing, etc.)
  - Practical considerations of scheduling work
  - Interaction and coordination with other contracts
  - Project acceptance
- OPEN TO PROSPECTIVE BIDDERS
  - Question and answer session
- ADJOURN

The prebid conference must be more than just a forum for responding to questions from prospective contractors. If a prospective contractor finds an obvious defect in a drawing or sees an ambiguity in the specifications, the contractor should ask for a clarification or amendment. But these questions might not be asked. As previously discussed, the nature of the competitive bid process is such that, to stay in business, contractors must first win projects (i.e., furnish the low bid) and then complete the job in such a manner that a reasonable profit is realized. If a prospective contractor identifies a potential problem or conflict in the contract documents that can be used to lower the bid price (and then to receive extra compensation during construction through change orders), the bidder may not bring the matter up during a prebid conference. To do so would expose it to all of the competitors, thereby negating the competitive advantage.

The conference should be scheduled far enough in advance of the bid date to allow adequate time for bidders to incorporate any new information (e.g., contract addenda) in their technical submittals or bids. All questions and answers, statements, and clarifications made during the prebid conference must be documented (i.e., minutes, addenda) so that they become a matter of public record, and can be referred to if problems or disagreements arise during construction.

CONSTRUCTION MANAGEMENT

As with any process, the construction management framework consists of both formal and informal elements. The formal requirements and channels-of-communications should be addressed and clearly defined in the specifications, including:

- Contractor superintendence.
- Project engineer's duties and responsibilities.
- Inspection requirements and inspector's duties and responsibilities.
- Process for submittals, reviews, approvals, and resubmittals; including turnaround times.
- Processing change orders and claims for extra work.
- Meetings.

It is emphasized that these formal elements apply equally to both parties of the construction contract -- the contractor and the contracting agency. A frequent complaint by contractors concerns the delays incurred while the agency reviews submittals (e.g., shop drawings, test procedures, etc.) and processes change orders. If these delays are unreasonable or greater than the specified time, then the contractor will likely be entitled to an extension of contract time, and possibly additional compensation. Furthermore, such delays can endanger good working relationships. The agency and other involved parties must therefore respond promptly to all written correspondence from the contractor. Not only is this contractually required, but timely responses also keep the pressure on the contractor to perform, thereby helping to ensure that the project moves along productively.

Obviously, it is in everyone's best interest if the formal channels of communication can be streamlined as much as possible. One possibility is to have the "official" submittals sent to the contracting agency with copies also delivered to all reviewing agencies (e.g., State, FHWA, construction/engineering consultants, etc.). In this manner, the time spent solely for the transportation of the documents can be minimized.

Human Relations

The ultimate success of the system implementation phase depends on the informal elements of the process -- specifically the experience, knowledge, cooperation, fairness, and commitment on the part of all participants. In fact, there is perhaps no other aspect of the system process where the relations between the individuals involved are so important. For example, there have been instances where the contract documents were less than ideal (e.g., split responsibilities, ambiguity, incomplete testing provisions, etc.); but because the individuals maintained good relations the traffic control system was successful. At the same time, there are other examples where the specifications and plans were quite good in terms of their accuracy and certainty, yet one or more individuals involved in the process adopted an antagonistic and confrontational posture, with the result that major problems occurred.

Such exceptions are not meant to diminish the need for well-written specifications and accurate plans. Rather, they illustrate the critical importance of good human relations during system implementation. There will always be some interpretation of even the best contract documents -- the contractor generally viewing them as the maximum requirements while the owner considers them to be the minimum requirements. The best way to resolve any differences in interpretation is through cooperation and compromise. All persons involved in the implementation process would do well to review and follow the principals for good human relations summarized in previous table 1.

Successful construction management consists of being fair, but firm. The "hard nose" approach in which the project engineer and inspectors exhibit an unyielding insistence on the "letter of the specifications," allowing no deviations no matter how justified, will seldom produce a successful system. At the other end of the spectrum, token ineffective management and inspection will also likely yield unsatisfactory results. Laxity and permissiveness in contract supervision will lead the contractor to believe that shortcuts or substandard workmanship will be tolerated, resulting in an unsuccessful system.

A major factor which is frequently overlooked or ignored in construction management is the need to establish a common goal. The most successful projects are those in which the agency gets the best job at the lowest cost, <u>and</u> the contractor realizes a profit. In other words, the best approach to construction management is one of "win-win" between the agency and the contractor.

Meetings

As discussed in the chapter 2, the absence of good human relations can often be attributed to poor communications. Meetings can be very useful in establishing and maintaining the necessary lines-of-communication. Not only do they provide a forum by which information can be readily exchanged, meetings also promote face-to-face contact which is so essential to good human relations.

Preconstruction Meeting

Prior to the issuance of a start-work order, the agency's representatives (project engineer, inspectors, etc.) should meet with the contractor's representatives. The purpose of this preconstruction meeting includes:

- Reaffirming roles and responsibilities of each party.
- Specific and direct dialogue regarding the contract documents and each party's interpretation of the specifications.
- Reviewing acceptable procedures for the construction work, for the associated inspection, and for project administration (e.g., circumstances that could lead to a work stoppage, procedures for originating charge orders, submission of invoices and technical submittals, etc.).
- Reviewing what is expected from the contractor.
- Establishing rapport and effective lines-of-communications between the contractor and agency.

It is also beneficial if, during the preconstruction conference, the project engineer exhibits his familiarity with the contract documents and demonstrates that the contractor may expect a fair (but firm) judgement and interpretation of the specifications.

Accurate minutes of the preconstruction conference, along with a roster of all attendees, should be kept. In the event any differences between the agency and the contractor arise during construction, the minutes can be referred to as an aid in settling the differences (assuming of course that the specific section of the specification was addressed during the conference). An initial site inspection with the contractor prior to the start of construction may also prove beneficial. In this manner site-specific issues can be discussed and resolved. As with the preconstruction conference, accurate notes and minutes of the site inspection are a must.

Periodic construction meetings should also be held. A requirement for biweekly or monthly construction meetings can be included in the general provisions of the specifications. Attendees at these meetings should include, as a minimum, the engineer, the chief inspectors, and the contractor's on-site representative. Other individuals, such as the owner, the owner's technical representatives, maintenance and operations personnel, and additional contractor personnel, should also participate in these meetings as appropriate. The meeting discussions should include:

- Project status (submissions and approvals, equipment deliverables, contractor's progress as compared to schedule).

- Planned events (type and location of work to be performed prior to next meeting).
- Contract requirements pertaining to planned work (e.g., pending submittals and/or approvals required to continuance of a task.
- Quantity estimates.
- Potential problems or conflicts, and alternative solutions.
- Request for change orders (prior to their official submission).

Engineer

A key player during the construction management effort is the project engineer. The engineer has a many-sided responsibility. As the authorized representative of the owner, the engineer is concerned with all of the owner's interests in the system construction and equipment procurement contracts. In this role the engineer, with the help of a staff of inspectors, reviews contractor submittals, approves construction methods, watches the work to assure that the workmanship is satisfactory and that no defective materials are used, makes monthly measurements of the work completed and reports to the owner the amount of payment due the contractor, conducts component system acceptance tests, and generally enforces all requirements and provisions of the plans and specifications. Most of the engineer's time should be spent on-site, and close contact with the contractor's superintendent should be maintained. However, the engineer should avoid exercising direct and complete control over the contractor's operations. Otherwise the independent-contractor relationship with the owner may become a master-servant relationship, which could relieve the contractor of certain obligations and impose unanticipated liabilities on the owner.

A more important function of the engineer is that of arbiter of the contract documents. The engineer must interpret the requirements of the plans and specifications, and serve as an arbitrator of disputes between the contractor and the owner. The engineer's decisions as to facts (but not law) are binding on both the contractor and the owner. As such, it is imperative that the project engineer be impartial, honest, and fair in such matters, even if it means deciding against the agency for whom the engineer is an agent or even an employee.

Expertise and the proper attitude are critical qualities in a successful project engineer. The engineer must have an intimate knowledge of the contract documents, and possess both systems knowledge and construction experience. The systems knowledge is necessary for overseeing the technical requirements of the contract documents, while the construction experience is necessary for administering the general (i.e., procedural) provisions.

There are numerous examples of implementation problems and delays occurring simply because the engineer (as well as the inspectors) were totally unfamiliar with the electronic components and software complexities associated with traffic control systems. These construction managers, who were otherwise very competent (i.e., significant experience with bridge and roadway projects), had no recourse but to base their decisions on the "letter of the specifications" when system knowledge and engineering judgement were called for. Similarly, problems have arisen when construction management responsibilities were assigned to system engineers who did not possess the necessary contract administration experience.

This combination of systems knowledge and construction management experience is seldom found in a single person. Thus, a team approach is usually necessary to assure that the project is successfully managed. For example, in one system, a contract administrator from the Construction Bureau of a State DOT was appointed the project engineer; and he alone could approve change orders and changes in work. The other members of the construction management team consisted of staff from the Traffic Control Systems Unit of the Department; and they were given free reign for approval of matters within their particular areas of technical expertise, and also advised the engineer on other matters. Other system projects have used a similar arrangement for project management, except that consultants were utilized to provide the necessary system's expertise and advice during construction.

Successful application of the team approach requires close liaison and good human relations between all members of the construction management team. The responsibilities and authority of each participant (e.g., approve catalog cuts, issue change orders, deviate from plans and specifications due to field conditions, final approvals, etc.) must be clearly spelled out, and the channels of communication identified. The development of the construction management team should commence during the planning and design phases. Additionally, the contractor should be made aware of the various authorizations and responsibilities to avoid any confusion during construction.

When consultants are being used for technical advice, they should play an ongoing role. If consultants are not brought in until a crisis has arisen, they will not have the project background needed to make an optional contribution. It has also proven useful if the consultants are permitted to talk directly with the contractor. Finally, all team members must always be kept informed of the project status and any developing issues, and be involved in the decision making process as appropriate.

Another important consideration is the attitude of the project engineer. The project engineer should be someone who is willing to take responsibility for making things happen, and who will take great pride in a successful outcome. This person must be assertive and firm, but also be fair. Successful construction management requires give and take, and unbiased thinking.

Inspection

The purpose of inspection, as the term implies, is to inspect the contractor's work to ensure that it meets the requirements of the contract documents. Responsibilities of the inspectors include measuring quantities, record keeping, testing, and observation of the contract's work.

The need for thorough inspection does not imply that the contractor is incompetent, or worse, unscrupulous (although this does occur); but even careful and competent people can experience lapses and show negligence in some part of the work. For example, table 11 lists a number of recurring construction errors related to electrical work that have been experienced by a number of agencies. The errors on this list indicate that a multitude of things can go wrong on a relatively straightforward signal installation job. The potential for mistakes on a complex traffic control system project -- with miles of communications cable, sophisticated electronic hardware, and software -- is significantly greater. Regardless of whether such errors are the result of an honest mistake, carelessness, incompetence, or even premeditation; if errors are not discovered until final inspection or later during maintenance, costly rework or repair may be required, resulting in a less-than-successful system.

Thorough and competent inspection is crucial to the success of a traffic control system. It is imperative that an adequate number of inspectors be provided to oberve all of the contractor's activities. Furthermore, some or all of these inspectors must be qualified in the electrical and systems area. Given the great advances that have

Table 11. Recurring construction problems related to electrical work. [6]

CONDUIT INSTALLATIONS

- Minor bends in conduit without proper use of bending tool, causing partial collapse of conduit and resultant problems pulling wire through conduit.
- Use of rocky material for conduit backfill instead of fine soil or sand which results in eventual collapse of conduit.
- Failure to clean dirt and moisture from conduit prior to pulling wire.
- Failure to cap stud ends and free ends of conduit resulting in intrusion of soil and moisture.
- Conduit buried at less than required depth causing future maintenance problems such as inadvertent cutting or mashing of conduit.

FOUNDATIONS

- Improper or wrong-size anchor bolts installed or installed out of alignment for proper pole base plate fit.
- Improper backfilling or lack of mechanical tamping around foundation may result in eventual tipping of the foundation and pole.
- Failure to grout under the base of pole.
- Failure to check plans for foundation size and construction in accordance with standard drawings.

WIRING

- Failure to use a wire lubricant prior to pulling through conduit may damage wire, installation, or the conduit.
- Use of extreme force and speed to pull wire as with a vehicle may damage wire, insulation, or the conduit.
- Unauthorized splices in buried or concealed junction boxes that create future maintenance problems.
- Failure to use insulated bushings at conduit entrances to metal junction boxes, cabinets, and so forth will scuff insulation from the wire when it is pulled.
- Use of wrong type or size of wire or wire with improper insulation.

LOOP WIRING

- Improper splicing of loop detector lead-in wire which may break down causing moisture to enter the splice and ground the loop making it inoperable.
- Use of a sharp instrument such as a screwdriver to force loop wire into the sawed slot causing damage to the wire or insulation.
- Failure to hold loops at the bottom of the slots while applying sealant.

occurred in electronic and systems technology, coupled with an emphasis in most transportation agencies on roadway and bridge projects, the necessary construction and systems inspection is not always provided, often resulting in significant problems and "failures". There are ways for overcoming this situation:

- Establish a small group of inspectors who are trained and assigned to handle systems work. This is feasible only for those agencies (e.g., State DOT) which plan to fund and manage several system projects over a number of years. Another consideration is the ability to assign members of the system inspection group to other duties within the agency when there is limited or no system construction underway.

- Supplement the regular construction inspection force with technicians who have electronic's knowledge (e.g., the persons who will be maintaining and operating the system once completed.) This method is analagous to the construction management team previously discussed. The duties and responsibilities of each member of the inspection team must be delineated. Furthermore, the agency must hire the system operations and maintenance staff early in the process (i.e., design phase), and then provide training in contract administration and inspection prior to the start of construction. A potential drawback of this approach is that during a major system expansion, these technical personnel will be unable to perform their normal system duties while administering and inspecting the expansion contract.

- Use contract inspection services. This approach has also proven successful. One form of contract inspection is to hire a systems consultant to supplement the agency's inspection force and provide systems expertise during construction. The responsibilities of the system consultant can be extended to include all contract administration -- construction inspection as well as the role of "engineer". As previously discussed, such an arrangement is necessary with the systems manager approach -- the systems manager assuming all construction management duties in conjunction with his overall responsibility of providing a fully operational traffic control system. The arrangement can also be used with the engineer-contractor approach and sole-source procurements.

When contract inspection and engineering services are used, the system consultant becomes an agent of the owner. It is good practice to state the terms and conditions of the relationship in a written agreement. The agreement should address, as a minimum, the following:

- Who is the official contracting agency, the engineer, etc.

- Final approval regarding contractor submissions, extra work, test results, etc.
- Authority to deviate from the plans and specifications, to change quantities, to issue written change orders, resolve disputes, etc.
- Any restrictions or requirements as to interorganization communications (consultant-contractor).

The contractor should also be made aware of the terms of the agreement to avoid any confusion during construction.

Regardless of the manner in which construction inspection is provided, it is imperative that the inspection force have the appropriate knowledge and expertise, that they be on hand before the start of construction, and that a sufficient number of inspectors are available so all work is thoroughly inspected and the contractor's progress is not delayed.

Additional Compensation

A dichotomy of the low-bid process is that the contractor who wins the project also has the greatest risk of losing money. Contractors base their bids on the conditions identified on the plans and the requirements in the specifications; or rather, their interpretation of these contract provisions. Should these conditions and specified requirements change or prove erroneous, or should the contractor's interpretation be different than the engineers, then the project may start to cost the contractor more than originally anticipated as reflected in the bid. Given the low bidder's minimal tolerance for being subjected to additional costs, the contractor can easily end up in an unprofitable situation. Since profit is a precondition to a contractor's continued existence, the construction manager can expect to see change order requests and claims for additional compensation.

Most requests for extra compensation result from the contractor's contention that extra work and materials were required by reason of errors in the contract documents, changes, additions, delays and the like during the course of construction. It is the engineer's responsibility to determine if claims are legitimate and, if so, to determine an equitable value of the additional compensation. In general, a contractor is entitled to additional compensation under the conditions described below.

Actual Quantities Exceed Initial Estimate

Since it is the very nature of most unit-price contracts for the owner to agree to pay the contractor for each unit of work accomplished and/or material installed, this is usually not a problem. It is noted, however, that severe budgeting problems can occur if it becomes necessary to significantly increase certain quantities during system construction (e.g., install several miles of additional new conduit because existing conduit called for on the plans is unusable).

Reduction in Quantities/Elimination of Work

The contractor is usually not entitled to compensation for loss-of-profits resulting from the actual quantities being less than originally estimated, or elimination of entire items of work. This assumes, of course, that the specifications give the engineer the right to reduce quantities and to omit portions of the work. There are exceptions to this general rule. The elimination of work cannot alter the main purpose of the contract (i.e., to install a traffic control system). Furthermore, the contractor may be entitled to an adjustment in the unit price of an item if the reduction in quantities increases the cost of procuring or installing the item (i.e., economy-of-scale). This often occurs with "high-tech" items, such as field communication interface units, where the supplier's development costs are independent of the number of units manufactured. A reduction in the quantity means that these development costs must be spread over fewer units, with a resulting increase in the unit cost.

Failure of Plans and Specifications

As previously noted, the owner impliedly warrants the sufficiency of the plans and specifications supplied to the contractor. A corollary of this rule is that the contractor is entitled to additional compensation for any extra work resulting from defective plans and specifications. Defective in this sense means that the contract documents are technically incapable of producing the desired result, or they make misrepresentations of essential facts and conditions. A frequent example of this are underground utilities which have been hit and damaged by the contractor, but which were not shown on the plans nor marked in the field. Generally, the contractor cannot be held responsible under these circumstances. Another example is the use of existing conduit for communications cable. If the cable cannot be installed in the conduit as specified (due to blockages, collapses, severe bends, too many bends between handholes, existing cables that are tangled, insufficient space, etc.), the contractor is entitled to additional compensation for the time and materials initially spent attempting to install the cable, for locating and identifying the conduit problems, and for any resulting delays to operations.

Work Beyond the Contract Scope

In general, a contractor who performs additional work not shown on the plans nor defined in the specifications (e.g., work not included in a pay item) is entitled to additional compensation if the work was requested by the agency. Following on with the unusuable conduit example, the contractor would also receive additional compensation for any repairs or other adjustments made to the existing conduit if such work had been directed by the engineer and was not included in the contract documents (e.g., no separate bid item for repairing or cleaning existing conduit). Extra work of this nature is often relatively minor, involving incidental items which were inadvertently left out of the contract documents -- for example, resetting a brick walk, or replacing an entire sidewalk slab (as required by local codes) when the specifications only require replacement of the trench width. However, there have been instances where the specifications were vague or incomplete concerning a major system item, resulting in substantial extra costs.

Delays Caused by Owner

A contractor is entitled to additional contract time for any delay to progress caused by the owner, the owner's agent, or another contractor engaged by the owner on the same project. If the delay results in increased costs to the contractor (e.g., maintaining staff on-site for a longer period, increases in labor rates due to inflation, lack of efficiency, etc.), the contractor may also be entitled to additional compensation.

The contract documents also apply to the agency, and the agency must be prepared to satisfy these requirements as to not interfere with the contractor's work.

Examples of delays which have been attributable to the owner or the owner's agents include failure to review contractor submittals within the specified time, failure to provide all government-furnished equipment (GFE) and installations in accordance with the contractor's schedule, failure to complete make-ready work for utility poles on time, failure to complete testing for acceptance, and incomplete or substandard work provided by other contractors hired by the owner in conjunction with system implementation. The latter situation might include a leased-line communication network that is not functioning properly when the contractor is ready to commence system integration, system detectors installed by another contractor which are inoperable, and a computer room contract that is still in progress when the central hardware is ready for shipment and installation.

Change in Manner of Performance

When the contract documents do not specifically describe the method of performance, the customary economical method is proper. If the contractor is directed by the engineer to perform in a more expensive manner than is customary, the contractor is entitled to additional compensation. As such, when advanced techniques are contemplated, they should be specifically provided for in the contract documents.

Discussion

It is emphasized that change orders are not necessarily bad. They provide the formal (i.e., legal) means by which the contract documents may be modified with a minimal impact on the system process. Some change orders must be expected during the construction process -- after all the estimated quantities can only be a close approximation; no design is ever all-inclusive and unknown conditions and additional work are bound to be encountered; and the participants in the system process, being human, are prone to changing their minds sometime during the process. At the same time, "significant" change orders can be avoided by thorough planning, accurate and comprehensive design, and firm (but fair) construction management.

As discussed in chapter 4, the specifications should clearly define the change order process. When change order requests are submitted, it is the engineer's and agency's responsibility to respond to them quickly. A determination that extra work has in fact been performed and the amount of any additional compensation must be agreed to as soon as possible, and a settlement processed. Delays tend to produce distortions and exaggerations. Resolving a claim at the end of the project is likely to be a costly and time-consuming endeavor.

Recordkeeping

The discussion so far has concentrated on managing the construction process such that problems and disagreements are minimized. Preparing accurate and definite contract documents, having qualified and knowledgeable people to perform and manage the system implementation effort, establishing and maintaining a common goal, having clear procedures for handling changes in the work, approaching differences in a reasonable and objective manner, and resolving problems fairly and equitably are all helpful in this regard. Still, disagreements do occur during the system process. Sometimes they can be quite unpleasant and even take place in court. For example, contractors have been known to underbid a project with every intention of making a profit through construction change orders. In other instances, contractors have contemplated the performance of the system contract by using a specific method which was not in accordance with the specifications, (e.g., "canned" software package), based the bid on the assumption that the method would be approved, only to find out after contract award that the method could not be used. It must also be recognized that differences in interpretation are always going to occur to some extent. If such circumstances arise, thorough and complete records are essential.

A sizable amount of paperwork can accrue during system installation, and keeping track of it takes time. However, this project documentation should not be taken lightly. It is an invaluable aid in managing a system installation project and in resolving disputes and problems. If major problems arise, such as those noted above, thorough recordkeeping may forestall litigation. In simplest terms, document everything and assume nothing. Worthwhile recordkeeping includes:

- Copies of all contracts, agreements, plans, specifications, and standard specifications referenced in the contract documents.
- Background information on the contractor -- following the bid opening, contact other systems where the winning contractor also worked; become aware of the contractor's attitude and operating history.

- Dated pictures of contractor's progress and problem locations.
- Minutes or transcriptions of every meeting.
- A log to record events, including all conversations (in the field and over the phone) with the contractor and the contractor's representatives, and with other involved parties.
- A checklist of specification requirements.
- Work order letter and written notice-to-proceed.
- Contractor-prepared schedule and periodic updates.
- Daily diary to record all project activities including the location and quantity of all items installed and/or stored, the materials tested, and the results of all inspections and tests.
- Material lists.
- Copy of the project plans, marked to indicate completed work and quantities.
- Records of payments to contractor.
- Regular status reports to the funding agencies (Federal, State, local, etc.).
- Changes or additions to plans and specifications; change orders.
- All project-related correspondence.

Substantial Performance

An important implied condition of contracts is the doctrine of substantial performance. This doctrine recognizes that, as a practical matter, strict and exact performance of the plans and specifications seldom, if ever, occurs in construction, system, or building contracts. The doctrine allows the contractor to receive payment for the contract services which were substantially performed.

A landmark decision involving the doctrine of substantial performance --Jacobs and Young v. Kent, 230 N.Y. 239, 129 NE 889 (192) -- included the following requirements for the application of substantial performance:

- "The deviation or defect must be minor in relation to the total project.

- The mistake must be inadvertent and not willful and not fraudulent.
- Compensation must be made for the variance in performance; nominally, the difference in value between the exact performance required and the performance given, or the cost of replacement whichever is more equitable."(5)

Quoting further from the reference, "the judges decision made it clear, however, that the doctrine of substantial performance should not be applied in every case of deviation, and stated that the doctrine was no general license to the contractor to install willy-nilly whatever he thought was just as good as that required in the contract. The mistake must truly be unintentional and trivial. The willful transgressor must accept the penalty of his transgression".

For the doctrine to apply, the deviation must not frustrate the objective of the contract, namely a fully operational system. The agency must have received substantially what it asked for in terms of quantity and quality of performance. Finally, both the contractor and the engineer should recognize that the doctrine of substantial performance is applied to ensure fairness to the contractor. It cannot be used by a contractor as shield for intentionally defective performance or for intentionally substituting cheaper or inferior materials or components.

The agency should be careful about expanding the system prior to final acceptance, when the system still "belongs" to the system contractor. Expansion under these circumstances could constitute a defacto acceptance of the system. Any remaining punchlist items might be considered "minor" within the context of the substantial performance doctrine, since these deficiencies did not prevent the owner from taking beneficial occupancy and expanding the system. This occurred in one system, with the result that all liquidated damages were waived and the contractor was relieved of all further maintenance responsibilities.

Claims

A claim is very similar to a change order, except that the claim usually occurs at the end of the project or following a stoppage of work. Thus, in many respects, a claim can be considered a change order that was never processed. The claim and change order processes are also very similar -- identify if additional compensation is justified, and then determine the appropriate amount of the compensation.

As previously noted, waiting until the end of the project to reach a settlement regarding an extra work dispute often leads to distortions. It is not unusual for the contractor to exaggerate the costs and to include superfluous items which are not even remotely justified. For example, in one system, a contractor's claim of over $3 million dollars was settled for approximately $800,000. Items in the claim which were denied by the agency included field engineering costs which had not been adequately documented; the cost of money (interest on delayed payments) and additional bonding costs on the grounds that they were included in the contract items; the uncompensated portions of previous change order requests as well as the extra work which had already been compensated; and the costs of preparing the claim. In another system, a $600,000 claim was settled for $25,000.

The size of a claim is not limited to its dollar amount. The paperwork can also be quite large. While this can make the review effort quite tedious and time consuming, close scrutiny of the contractor's claim by the agency is a must.

The claims process does allow the contractor and the agency to "agree to disagree" on their respective interpretations of the specification requirements without significantly impacting the system installation progress. The scenario described in previous Case Study Example No. 1 (chapter 4) is fairly typical -- the engineer directs the contractor to proceed with the work in accordance with the agency's interpretation or be in default; the contractor then usually proceeds with the work and files a written notice of the intent to file a claim. The system construction process continues, and the disagreements are resolved after the system has been installed.

In the final analysis, claims are seldom beneficial to either party and they should be avoided if at all possible. The best way to accomplish this is through definitive contract documents and good human relations during construction. However, a singular interpretation on all matters is seldom possible and personalities sometimes conflict. Accordingly, the claims process should be addressed in the specifications.

In the event it becomes necessary to declare a contractor in default and to select another contractor to complete the work, the following points should be considered:

- The specifications must describe the procedures for defaulting one contractor and choosing another. Reasons for declaring a contractor in default might include:
  - Failure to provide sufficient materials to enable proper prosecution of the work.

  - Discontinue prosecution of the work they had contracted to perform.

  - Failure to resume work which had been discontinued.

- When taking work out of the hands of a contractor, these provisions must not be violated since the contractor agreed with these procedures when the contract was signed.

- The documents provided to prospective new contractors should describe current conditions -- what has been installed, what is in storage, what has been tested and what were the test results, etc.

- The new contractor must use the same specification. Any attempt to change the original specification opens the agency up to charges that the specification was arbitrary, not clear in its definitions and meanings, and impossible for any contractor to fulfill.

AGENCY INVOLVEMENT

The importance of the local agency being an active participant during the system installation phase cannot be overemphasized. Even if all of the installation is accomplished by a contractor(s), and a consultant/system manager provides all construction engineering and inspection services; the local agency, as a party to the contract, must be prepared to become heavily involved. The management responsibilities of the agency include:

- Processing reviews and approvals of shop drawings and other contractor submittals within the specified time period.

- Processing contractor claims and change order requests.

- Stating decisions clearly and consistently.

- Maintaining timetables for agency-supplied items and work by others, such that the contractor is not delayed.

Participation is also critical during equipment installations, data base preparation, acceptance testing, and training. As is discussed in the next chapter, this involvement will be very beneficial in terms of operating and maintaining the system.

A major emphasis should also be placed on public information. Press releases and possibly press conferences at the commencement and completion of key stages of the system implementation process may be beneficial. A public information strategy is particularly critical for freeway surveillance systems since many, if not all, of the control strategies (variable message signs, ramp meters) will be new to the motoring public. Questions that may be raised include: is the sign message mandatory, does a green ramp meter signal give the motorist absolute right-of-way to enter the freeway, are the meters enforceable, etc. Meetings with neighborhood groups may also be needed relative to ramp metering, followed up with communications once the meters have been turned on.

SYSTEM INTEGRATION AND START-UP

System integration is the merging of the various hardware and software subsystems into an operational traffic control system. The responsibility for this work belongs to the contractor or system manager, depending on the procurement approach.

System start-up is the process necessary to assure that the traffic control system operates effectively and achieves optimal performance. The start-up process is accomplished in a limited time period immediately after system integration, and includes evaluation of the hardware, software, and system performance; completion and updating of basic data needed to operate the system; and any modifications or corrections needed to improve system performance. The costs of system start-up, other than those attributable to routine operation and maintenance, are eligible for Federal-aid funding.

An important aspect of the system integration and start-up process is the software and system testing. It is usually desirable for representatives from the agency to visit the contractor's/system manager's facility to review the software activities. This review should include the continuing observation of the documentation process to ensure that all the required information is being included and that the documentation truly reflects the coding that it represents. More importantly, the agency must review the input/output performance that is associated with the system.

An initial check-out of the central subsystem (i.e., computer, communications hardware, and applications software) should be performed. The tool for conducting the software test is the acceptance test plan. This plan is usually developed by the contractor/systems manager, and must be thoroughly reviewed by the agency before approval. Attributes of a successful test plan include:

- All specified software features and functions are included to verify proper operation, including benchmark tests of the ultimate system size.

- Tests are organized into a set of functional categories. If an incorrect software operation is identified, the necessary modification should be made as soon as possible, and the entire series of tests within the category should be conducted again to ensure that the correction did not cause a new malfunction elsewhere. These categories are a function of the software structure. For example, correction of an error in processing of detection data could potentially affect detector error processing, traffic responsive operation, critical intersection control, etc.

- Test procedures identify necessary test equipment (e.g., test controllers, detector simulator, etc.), and personnel requirements (e.g., system operator, observers, etc.)

- Each test description includes:

  - Functional description and objectives.

  - Specification and operator's manual reference.

  - Step-by-step operating instructions and procedures (e.g., commands to be entered, CRT displays to be observed, reports to be reviewed, etc.).

  - Any data reduction procedures.

  - Criteria for passing the test (i.e., functions are satisfied and constraints are not violated).

  - Space(s) for the agency to sign-off (name, date) that test has been passed.

  - All required test forms and report examples.

The acceptance test plan must be read and understood by all test participants prior to performance of the software test. Additionally, a thorough knowledge of the Operator's Manual is usually critical to the performance of this test, and an updated copy should be available to the operator at all times.

After the central hardware and the various field components have been integrated together, it is important to test the entire system under actual traffic conditions prior to acceptance. This final acceptance test typically requires 10 to 30 consecutive days of "trouble-free" system operation. As previously discussed, the contract documents must define the requirements for the software acceptance test plan, specifically address what the final acceptance test will entail, and specify the conditions (i.e., failures) under which the final test will be suspended or terminated.

Owners and contract managers must recognize that traffic control systems are very complex, containing sophisticated hardware and software. Some debugging is always necessary. The occurrence of such problems should therefore be anticipated and accepted as part of the system integration and testing process.

Computer-based traffic control systems require an extensive data base on which to operate. Problems have been encountered during several projects in that the specifications did not address who was responsible for the necessary traffic surveys, timing plans, and the development, coding, input, and debugging of the data base information. Without a clear definition of the responsibilities, the user will likely be responsible for more than expected. While there are no rules as to who is to develop the timing plans and data base, the responsibility must be assigned to a specific organization.

Even if the contractor/systems manager is responsible for timing plans and data base development, the agency should participate in this effort to review the timing plans that will eventually be implemented on the street, and for the purposes of training. Additionally, the scheduling of timing plans and data base development is also important because the plans must be available during the final system acceptance testing.

SYSTEM EVALUATION

Evaluation of a new traffic control system should always be performed to determine if the new system meets the goals and objectives identified during the planning phase, and to identify any timing plan deficiencies. The system evaluation can range from a "windshield observation" to a full-fledged study in which data are obtained, analyzed, and summarized in a formal evaluation report. The common formal evaluation technique is to use before-and-after measurements of traffic flow quality (e.g., speeds, travel time, delays, stops, etc.), although simulation analyses have also been utilized.

The formal evaluation study and report is highly desirable. Not only is it comprehensive, but the evaluation report can serve as a mechanism for disseminating information of value to citizens, decision makers, and other system users. Evaluation considerations include:

- Evaluate and determine the effectiveness of any real-time control strategies (e.g., traffic responsive operation, CIC, 2GC).
- Evaluate systems at the earliest possible date that will reflect stable operating conditions. If at all possible, both the before and after evaluation studies should be conducted under similar traffic conditions (e.g., perform both sets of measurements after the system has been installed -- the before study with the system off-line).
- Carefully check out and fine tune all timing plans and control algorithms prior to the start of the evaluation period.
- Conduct the evaluation during evenings, weekends, and special events, as well as during normal weekdays of operation to evaluate the benefits of the increased flexibility (e.g., large number of timing plans) of the traffic control system.

It is recommended that the results of the evaluation be documented and disseminated to provide user experience to other agencies considering such improvements. While the FHWA no longer requires an evaluation of new traffic control systems, the FHWA does support evaluation to the extent that Federal-aid highway funds can be used for evaluation activities.

In addition to evaluating the traffic control system proper, the system process should also be reviewed and evaluated following completion of the system project. Any problems in system planning and design will generally not become apparent until the project has been constructed. Thus, there needs to be feedback to the designer at this point so that any necessary improvements can be incorporated in the next set of contract documents. This is best accomplished by a regular process of cooperative review involving the agency, project engineer, construction inspectors, and the original designers.

6. SYSTEM OPERATIONS AND MAINTENANCE

After a traffic control system has been installed, tested, and accepted, the key to its continued success is an effective program of operation and maintenance. This requires an adequate staff of well-trained personnel, up-to-date documentation on all system components, adequate budget for spare parts and expendables, and a long-term commitment on the part of the agency to utilize the system to its full potential, including keeping the timing plans up-to-date on a continual basis. A "set-it-and-forget-it" policy will not work.

An effective operations and maintenance program is not easy. While the system is expected to operate on a continuous basis, it must do so in a very demanding physical environment which subjects components to extremes in weather, temperature, electrical noise, and disturbances, as well as possible physical damage from vandalism and accidents. The system's operational environment is perhaps even more demanding. Traffic flows and roadway networks change over time, and this means that new timing plans need be developed, input to the system, and fine-tuned on a continuing basis. Furthermore, daily operation of the system is in full public view of both drivers (who are directly affected by it) and decision makers who are responsible for allocating the funding so necessary to its continued success.

OVERVIEW

In general, the quantity and technological complexity of equipment associated with computer-based traffic control systems can represent a significant increase in operations and maintenance activities. For example, the enhanced hardware-failure monitoring and detection capabilities provided by today's advanced systems require a higher and more responsive degree of remedial maintenance. An additional level of troubleshooting may also be necessary to determine whether reported failures are related to hardware or software. Similarly, even though many traffic signal systems are designed to operate in an unattended mode, their increased flexibility demands additional operator involvement. Some agencies have misjudged the maintenance and operation requirements of traffic control systems and, consequently, have underestimated the staffing and budget needs; only to find out after system acceptance just how wrong they were.

The successful operation and maintenance of a traffic control system must be an integral part of the entire system process from the very beginning. This section presents general guidelines for developing and managing an effective program for operating and maintaining successful systems.

Planning

As discussed in chapter 3, the operational and maintenance requirements of the selected system must be in balance with the availability of personnel and budget resources. A particular system alternative may offer the most benefits in terms of traffic flow improvements and management of the transportation network. Its total life cycle cost may also be relatively reasonable. But if the agency's budget and manpower simply won't allow adequate maintenance and/or operations, then another system alternative should be selected.

The planning phase must therefore include an analysis of the maintenance and operations requirements for each system alternative. This analysis includes an assessment of the exiting maintenance and operation capabilities in terms of personnel, skills, and equipment; determining the necessary skills and work load impact of each system alternative; comparing the existing conditions with what is required for the various alternatives; analyzing the deficiencies; and establishing the feasibility of providing the additional operational and maintenance capabilities (personnel, skills, equipment, etc.) required for each system alternative. In essence, the planning process must provide answers to the following questions:

- How much additional effort is required to operate and maintain each system alternative, and at what skill level is the work?
- Does the existing staff have the capability to operate and maintain each alternative? If not, is retraining possible and/or will new staff be required?
- What are the cost implications of the operation and maintenance requirements?
- Should a given alternative be deleted or modified because of maintenance or operations personnel requirements?
- Is contract maintenance and/or operations a viable alternative?

Any operational and maintenance trade-offs must also be evaluated. For example, control strategies which incorporate automatic timing plan updates (e.g., 1.5 and 2nd generation control) will eliminate much, if not all, of the operational effort and costs associated with manual timing plan development. However, these advanced systems require a significant number of detectors -- an average of 1-2 per intersection -- that must be adequately maintained for this feature to work properly.

The operational and maintenance requirements of the selected system must be addressed in the Operations Plan including:

- Requirements for additional staff, qualifications of these new employees, and when in the process they need to be hired.
- Training required for existing/new staff, when the training will be provided, and by whom (contractor, systems manager, equipment vendor, etc.).
- Necessary documentation.
- Duties of system operators.
- Test equipment and spare parts required for in-house maintenance activities, and how these items will be provided.
- Maintenance contracts.
- Costs (e.g., staffing, maintenance contracts, timing plan updates, replacement parts, utilities, etc.).

Finally, prior to the authorization of Federal-aid highway funds for system construction, a commitment by the agency to dedicate the necessary resources for system operations and maintenance (as documented in the Operations Plan) is necessary.

Design

The traffic control system must be designed in such a manner that it is easy to operate and maintain. Two of the most important design elements in this regard are the specifications for training and documentation, which are discussed in subsequent sections of this chapter. In addition to training and documentation requirements, there are other design elements related to system operation and maintenance that should be included in the contract documents. These design guidelines are discussed below.

The contractor may be required to provide on-site support for a given period of time (e.g., 6 months) after the system has been formally accepted. This continued assistance may be eligible for Federal-aid highway funding participation to the extent that it can be categorized as training or "start-up assistance". Specific contractor tasks which may be accomplished as start-up assistance include:

- Provide a systems engineer to assist agency operators in adapting the system to reflect the needs of the local traffic environment.
- Define and correct hardware and software deficiencies which can be discovered only through sustained operation.
- Assist in repairing and replacing failed system components necessitated by typical start-up mortality rates.
- Provide on-the-job training as an extension of formal training provided earlier.
- Prepare and provide updates for system documentation.

Any on-site support as described above should be included as a separate pay item and its duration defined.

Stringent testing requirements will enhance the long-term maintainability of the system. These tests should be correlated with the training and documentation requirements. For example, if successful completion of a hardware test will result in acceptance of a component, then the specifications should state that this test cannot commence until all required component documentation has been supplied and the associated training has been provided. Similarly, software/system testing should not commence until after the operations manuals have been delivered to the agency, thoroughly reviewed by the operations staff, and accepted.

Additional hardware and software can be incorporated in the contract documents to enhance system operations and maintenance. For example:

- Provision of spare parts. This requires FHWA approval for Federal-aid projects and must be a nonparticipating item.
- Test equipment (e.g., oscilloscope, digital multimeter, and test panels for controllers, RCUs, and detectors, etc.)

- Remote peripherals (e.g., CRT, real-time graphics display, printer) located at the maintenance shop. These devices can be used by maintenance personnel to immediately identify locations that have failed and the nature of the failure. A cellular telephone, modem, and portable CRT/keyboard may also be provided in maintenance vehicles.

- Simulation hardware and software which allow operators to interact with the system and go through the actual motions of system operation (e.g., change signal timing parameters, initiate variable message sign messages, etc.) without their actions being implemented in the field. This can also be a valuable training aid.

Maintenance personnel should be consulted throughout the design phase as to their needs and concerns. In general, it is important to design with maintenance in mind. Examples include:

- Specify modular components so that components can be swapped in the field and repairs handled back in the shop where they will not interfere with day-to-day operations.

- Specify environmentally-hardened components (e.g., meet NEMA specifications for environmental requirements).

- Standardize equipment makes and models to reduce the number of spare parts and the different maintenance techniques required.

- Specify self-diagnostic capabilities.

- Specify transient protection (e.g., power surges and lightning) and equipment grounding.

- Locate components such that they have a minimum vulnerability to damage (e.g., knockdowns of field cabinets).

- Provide for safe and convenient access to the hardware for maintenance personnel (e.g., will traffic lanes need to be closed when variable message signs are being repaired or relamped, ability to see signal displays from controller cabinet).

Maintenance responsibilities for all system components must be clearly specified as discussed in chapter 4. Additionally, warranty and guarantee requirements should be included in the specifications.

Software warranties should be strongly considered. Decision makers have erroneously presumed that software programs for traffic control systems require little or no maintenance following installation and initial debugging. Unfortunately, it is common for a software package to experience isolated failures or bugs. The logic paths are highly complex which frequently makes it impossible to test every possible path. The software warranty should reflect this fact.

Installation

Good preventive maintenance begins with and depends on proper installation; and as discussed in chapter 5, proper installation requires thorough inspection and testing of the contractor's work. The system operators and maintainers should participate in the inspection process and during acceptance testing. Such involvement is an excellent method of informal training, and also fosters the acceptance of the new system by these personnel.

It is imperative that all specified documentation and training be obtained during the installation phase. Submitted materials (e.g., manuals, training course outlines, etc.) should be closely studied to assure that all required documentation and training exists, and that it is complete and clear to the agency personnel. The documentation must be also kept updated throughout the system installation phase to reflect any hardware or software modifications. Complete and up-to-date documentation is so important to a successful system that the Traffic Control Systems Handbook recommends withholding final payment for the system project until acceptable final documentation has been provided. (3)

ORGANIZATION AND MANAGEMENT

Providing adequate technical staff and budget resources for system operations and maintenance is critical for a successful system. Management must be made aware that the investment in a traffic control system is not simply a one-time expense for design and installation, but rather a long-term commitment requiring continuous support. The sophistication and capabilities of a traffic control system seldom reduces the size and technical capabilities required of the operations and maintenance staff, and it is a serious mistake to assume that this will be the case. A commitment to providing the necessary personnel must be made, followed by the hiring of the additional staff and staff training.

The timing of any staff additions is very important. Sufficient lead time must be allocated for establishing new positions, developing position descriptions and salary classifications, recruitment, hiring, and training so that the needed personnel are available and ready at the appropriate time in the system process. The agency's system supervisor should be employed (i.e., designated/hired) no later than the start of the implementation phase of the project. Other operations and maintenance personnel need to be employed during system construction such that they may receive the training provided by the contractor/system manager, review documentation, and participate in system testing. If these persons are to assist with construction inspection, they need to be hired even earlier.

Organization

It is generally recommended that a traffic control system be integrated into an existing traffic engineering and transportation department or equivalent. The responsibility for managing and supervising the traffic control system should be clearly designated to a specific individual or position, and should encompass both operations and maintenance. This logical tie-in assures a unified effort. Successful operation of a system is not possible without proper and effective system maintenance. Likewise, system maintenance cannot be properly performed without input and cooperation of the operational personnel. It is the responsibility of management to organize these operations and maintenance personnel into a single cohesive team in which information flows freely between work segments, cross-utilization of personnel is possible, and the system staff are responsive to the requirements and needs of the system.

Locating the maintenance function in another unit which is separate from the traffic control system operations and engineering unit (e.g., electrical services unit) may create a situation in which the efficiency and full utilization of the system are not adequately emphasized. This type of organizational arrangement has been successfully used in several systems; but each unit must have a specified assigned area of responsibility, and a good working relationship must be established and maintained between the different units.

Management

Good management of the operations and maintenance staff must begin during the planning and design phases. This is particularly true in terms of fostering an acceptance of the new traffic control system among agency personnel. Fear of the unknown, coupled with a potential misunderstanding of the system's purpose and concerns they may have regarding job security, can detract from full and efficient utilization of the new system. Opportunities for staff involvement can be provided throughout the prestart-up process, including:

- Early involvement in system planning and design to ensure proper consideration of reliability and maintainability issues.
- Assurance of thorough training tailored to staff needs, and then the actual training.
- Participation in construction inspection and acceptance testing.

After the system has become operational, retention of operations and maintenance staff is an important management function. Turnover of personnel -- the result of advancement to other positions or terminations of employment -- will always exist. Nevertheless, there are means by which staff continuity can be improved:

- Classifications and position descriptions for system managers, operators, and maintainers which adequately describe their work and reflect the unique aspects (e.g., state-of-the-art technology) of traffic control systems. It is noted that proper classifications are also necessary if and when it becomes necessary to hire replacement staff.
- Pay and benefits that are competitive with the labor market for similar technical work.
- Encouragement of professional development -- in-house training programs, attendance at relevant training courses and schools, challenging work with increased responsibilities and authority.
- A proactive environment as opposed to a reactive one. Promoting a sense of accomplishment; that traffic problems are being solved and that the public is benefiting from everyone's efforts.

- Wholehearted support for the system from upper management (e.g., Director of Transportation, Public Works, etc.). Listening to staff suggestions for improved operations and maintenance, and making the necessary efforts to obtain funding and authorization for these improvements.

Another aspect of managing a traffic control system is careful control and distribution of all documentation changes. Every change, no matter how trivial, must be documented. For example, it is essential that as-built drawings be updated to reflect all subsequent field changes (e.g., relocated cabinet, new power service, etc.). Additionally, the controller timing settings should accurately track the computer data base and vice versa. Completeness in documentation can be encouraged through the use of standard forms for each type of modification and update. It is also important that when one copy of a set of documentation is updated, all copies are updated.

Coordination with other agencies and organizations is very important for successful operations and maintenance. This may include:

- Police - Coordination and cooperation with the police department can improve the efficiency of the system in terms of minimizing ramp meter violations through enforcement, contacting the system operators regarding incidents (e.g., accidents) so that signal timings can be changed, traffic control during special events, identifying malfunctions which the system cannot monitor, and so forth. In a number of jurisdictions, the inservice training of police officers includes an indoctrination of the system, its capabilities, and what it can and can't do.

- Construction Sections and Bureaus - Other agencies and organizations will have construction projects which can severely disrupt system operations if proper coordination is not maintained (e.g., conduit containing communications trunk cables is cut during excavation and trenching, damage to system detectors, etc.). Provisions should be included in all roadway projects and utility agreements to cover repair or replacement of damaged system facilities. Since prevention is better than a cure, system personnel should be contacted prior to construction so that all underground facilities can be marked. (As is subsequently discussed, accurate as-builts are also very important in this regard.)

- Media - Communications with the media (press, television, radio, printed literature) can help keep the public informed of traffic flow conditions, and of the system's status and improvements. In one signal system, several radio stations broadcast their traffic reports from the control center. A freeway system has a standard agreement for radio and television stations and other remote traffic information users (e.g., private traffic reporting companies that sell their services to radio stations). Under this agreement the agency will connect the surveillance system computer to phone lines serving remote receive-only terminals. The agency will then supply these R-O terminals with expressway congestion reports on a continuous, 24-hour-a-day basis, as frequently as every 5 minutes. These services are at no charge. The radio station (et al) agrees to provide and maintain the terminals, modems, and terminals, and to report the traffic information with timeliness and accuracy.

Other management responsibilities and considerations include:

- Hosting visitors to the control center - a task which is usually most intense during the first 18 months of operations.
- Formulating consistent policies regarding system operations. This is particularly critical for variable message signs. Many systems restrict sign messages to incident management and related traffic information. Requests to use the signs for other messages (e.g., "WELCOME ___ ___ CONVENTION", "WEAR SEAT BELTS", etc.) are not uncommon, and are usually denied.
- Public relations. From a management point-of-view, a traffic control system is competing with other governmental services for funds. Accordingly, good PR (e.g., mention the benefits in talks, press conference for significant milestones, etc.) can be very important and beneficial.

DOCUMENTATION

Successful operation and maintenance of a traffic control system is dependent upon personnel having access to adequate documentation. Furthermore, the documentation must be easy to follow by future employees as well as those who have been through the training sessions.

Documentation needs to be specified for every system component and for every aspect of the system's operation. Additionally, this documentation must be provided in sufficient detail to fully describe the maintenance requirements, methods of operation, and the expansion/modification procedures. In essence, the documentation should satisfy the requirements of all personnel involved with the operation and maintenance of the system, including:

- Operators must understand the theory of system operation as well as the operating sequences to be performed during normal system operation, and the procedures to be followed in the case of system malfunction.

- Maintenance staff must understand the theory of operation of all of the electronics devices within the system. They must have installation procedures and parts lists, and they must known who to contact should problems arise. They must also have schematic diagrams, cabling plans, and any other details required to maintain the system.

- Programmers must be provided with detailed descriptions of software operation, including up-to-date source listings of the computer programs and descriptions of where everything is located in memory, so that functional modifications can be made as required.

- Traffic analysts must be able to modify the system data base to incorporate new signal timing plans and to expand the system.

- Traffic engineers will require additional information including summaries of system operation to be used for publications or planning purposes.

There are four basic types of documentation to be specified and ultimately provided with a traffic control system -- as-built drawings, hardware documentation, software documentation, and operators manuals.

As-Built Drawings

Despite all efforts to develop detailed and accurate construction plans during the design phase, there will inevitably be revisions or additions to these plans resulting from conditions which were not or could not be anticipated. The construction drawings should therefore be modified during construction to accurately depict all field locations (e.g., intersections, ramps, detectors, signs, etc.) and the control center as they were actually built or modified. The location of underground components (e.g., conduits, handholes, foundations, etc.) and their depth are particularly important. As-builts can be required of the contractor, or they may be developed by the engineer and inspectors. Other as-built plans to be provided include:

- Drawings of all cable runs (e.g., communications, signal, loop lead-in) showing number and types of cables, terminations, taps, and splices.

- List of cable pairs to each location showing pair identification and function.
- Splicing charts for all interconnect cable splices.

When major modernizations or system retrofits are planned, the redesigns need to be based on "as built" plans that have been kept current. If these are not available, the redesigns may be difficult to carry out or may not make full use of existing facilities.

Hardware Documentation

The contractor should be required to provide hardware manuals which describe the operational and maintenance details for all components and equipment. This hardware documentation should include the elements summarized in table 12.

Some agencies have also developed their own maintenance manual to supplement the detailed documentation. This manual provides a summary description and catalog cuts of all system hardware in a single document. Flow charts (figure 3) for fault isolation may also be included.

Software Documentation

Software documentation is required for updating the software to correct operating deficiencies or to expand the available software features. Good software documentation can be difficult to specify and to produce. The specifications must carefully describe its content, and the agency must monitor its development to ensure that it is accurate and complete. Software documentation may include the items summarized in table 13.

It is noted that the level-of-detail required in the software documentation is a function of the documentation's intended use. The software documentation presented in table 13 would be required if the agency intended to modify the software and system operation sometime in the future. If the user intends only to expand the system within the constraints of the existing system configuration, then the software documentation need not be as detailed and comprehensive. Flow charts and inputs and outputs would be required, but source code might not be necessary. It is important to remember that documentation costs money, and an agency should not pay for unnecessary documentation.

Table 12. Elements of hardware documentation.

- General description - General description of the component.
- Theory of operation - Detailed description of the operation of the component.
- Normal operating procedure - Description of the procedure for the routine operations of the component; including normal operating characteristics, voltage levels and waveforms measured at test points.
- Installation - Detailed description of physical and electrical properties of the component and other pertinent step-by-step information necessary for the installation and use of the equipment.
- Parts list - Listing and identification of various parts of the component.
- Schematic Drawings - Complete and accurate electronic schematics that specify component interconnection, component values, voltage levels, and component locations.
- Drawings of cabinet layouts, wiring diagrams and lightning protection. Wiring and cabling lists describing interconnection of all plugs, chassis, and other components. In addition, they must identify wire type, size, and color code. They should also identify connector type, pin numbers or terminal strip numbers, and test points.
- Mechanical details - Equipment layouts, physical dimensions, access points, and test points locations.
- Power supply cabling - A description of the power supply, the power distribution system, and the characteristics of the power supply. The power source and all protective devices in the power system must also be described.
- Environmental controls - Power, heating, cooling, and humidifying.
- Descriptions of all preventive maintenance activities for all system components, (e.g., computer, communications units, controllers, etc.). This information must include both the procedures and the frequency with which these procedures are to be performed.
- Description of emergency maintenance trouble shooting and diagnostic procedures. This documentation begins with a list of symptoms and proceeds through a series of analyses until the most common cause of the symptom is identified.
- A recommended set of spares and test equipment to be purchased by the local agency or supplied under the contract.
- Instructions on the use of computer diagnostic software furnished by the computer manufacturers for evaluation of the computer and peripheral equipment operation.

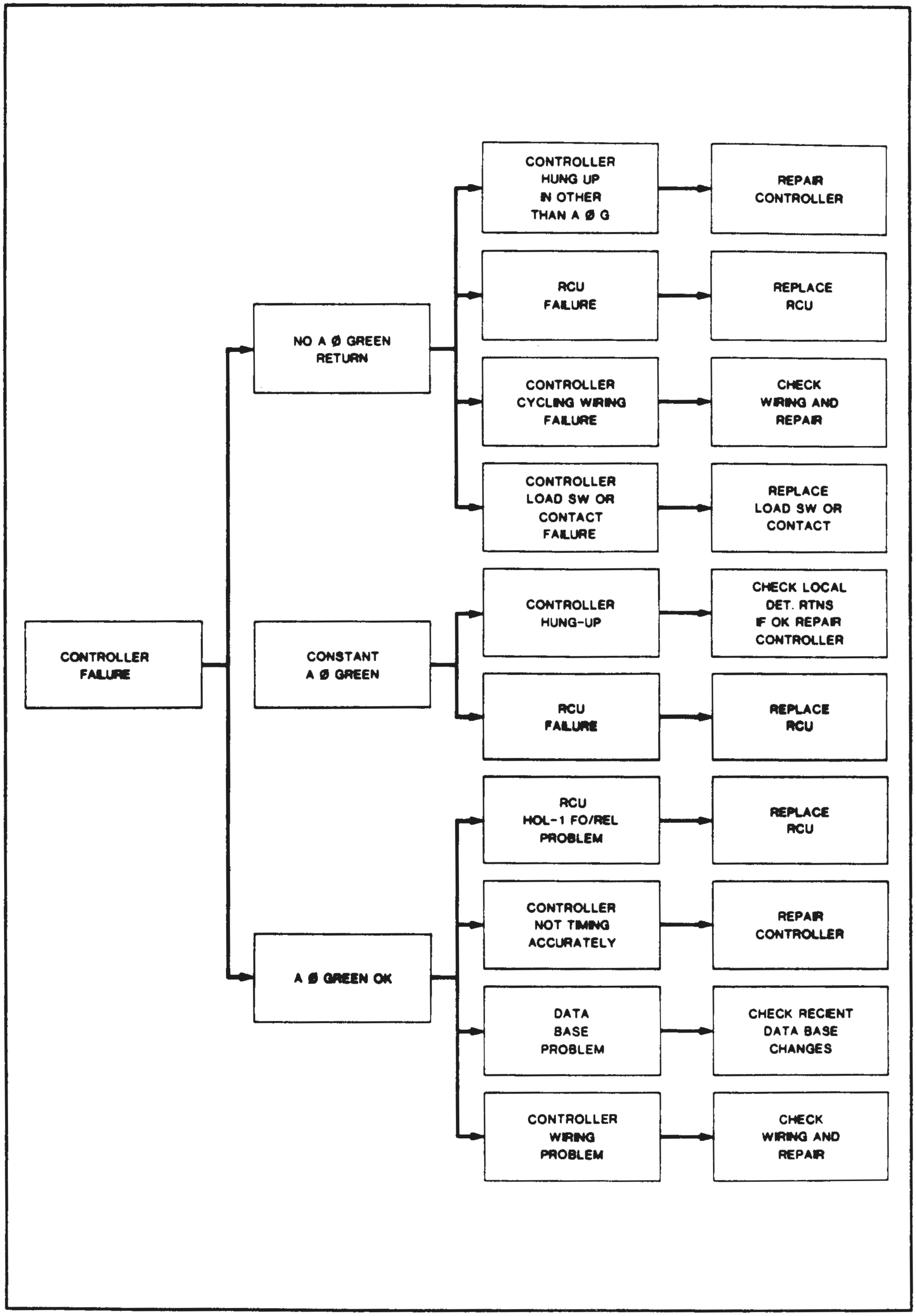

Figure 3. Sample fault isolation flow chart.
(Source: Winston-Salem, NC).

Table 13. Elements of software documentation.

- Source listings of the programs. These listings must be well commented to describe input/output, variables, purpose of subroutines, other lower level subroutines called.
- Flowcharts or HIPO's indicating the processing steps taken by every functional grouping of instructions. The flowcharts should be keyed to the software listings using instruction addresses and subroutine names. The flowchart must be preceded by a functional description of the subroutines purpose, storage requirements, and execution time.
- Descriptive discussion of each routine and subroutine in the application program and the data base update program.
- Lists that define every variable used in the software. These definitions must include variable name, its purpose, structure, and a list of the routines in which it is used.
- Maps showing the layouts of data and programs within the central computer, on disk, and on magnetic tape.
- A summary of system timing, including average execution times of all routines and average execution times of each priority level.
- All computer inputs and outputs, including addresses, command structures, data transfer rates, source/destination equipment, and printer and CRT formats.
- Tape-and disk-resident copies of the source programs along with hard-copy listings.

An issue related to software documentation is that of software rights. Some software, or sections of it, are proprietary to the supplier; and detailed documentation (e.g., source code) may not normally be provided. The software specifications should therefore specify the level of purchaser rights so that bidders can reflect these requirements in their proposal or bid. In general terms, the software rights will fall into one of the following categories:

- Proprietary software - The purchaser has no rights to proprietary software other than that provided by license or use agreement.
- Semi-proprietary software - The user (or purchaser) has no rights to semi-proprietary software unless needed assistance is not available from the supplier. Software documentation in such cases may be placed in escrow.
- User rights - The user has the right to use and modify the software only within the context of the existing system and configuration, or for an upgrading or expansion of the system.
- Full rights - Rights to use, modify, and transfer software are conveyed and restricted only as defined by specific agreement.

The specifications should also address the requirements of the software license agreement, including ownership, copy restrictions and rights (e.g., for backup, but not for selling/giving to other parties), limitations of use, transfer to other machines, modification of the software (enhancements) by owner or by third parties, and protection of information.

Operators Manuals

Operators manuals describe all the functional capabilities of the system and provide information that is required for the operator to carry out his/her tasks. The operators manuals should be developed to serve two concurrent purposes: a reference during system operation; and a self-teaching guide for new staff members. The information summarized in table 14 should be included in the operators manuals.

It is noted that some agencies have supplemented the operators manuals with additional material pertinent to their systems, including cross-references of each field location with the corresponding data base number, communications address and word, and map word; maps of CCTV coverage; procedures for keeping manual logs (failure, incident); radio responses, etc.

Table 14. Operators manual contents.

- Table of contents.
- Glossary of terminology and typographical conventions used in the manual.
- Operation of all interface devices (CRT terminal, graphics display) described in detail with respect to display of information, changing parameters, and operation of special keys or other equipment.
- Step-by-step procedures for every operational function -- equipment set-up, program loading and booting, start-up, shut-down, all system control commands, system monitoring, reports, displays, etc.
- Sample output formats -- reproductions of CRT screens, hard-copy reports, and displays; and what the information means.
- A complete list of trouble and malfunction indications with corresponding corrective, or emergency, action to be taken. Also included should be detailed descriptions of the various failure codes and how the respective filter values operate to determine failures.
- Data base descriptions -- input formats, generation procedures, output formats, and editing procedures. Step-by-step procedures for making data base changes or additions (e.g., add/delete controller or system detector, change controller type, reconfigure sections, set up traffic responsive, etc.) are particularly important.
- Alphabetical index.

Documentation Specifications

In addition to the contents of the various documentation, the documentation specifications should also address the following:

- Number of sets of documentation to be provided.
- When documentation is to be provided.
- Format of documentation (e.g., size of pages or plan sheets, type of binding, reproducible requirements).
- Agency review and approval.

The specifications may include a requirement for documentation testing. Documentation testing is an evaluation of how well the documentation serves the purpose for which it was intended. Several hypothetical scenarios and problems which require reference to the documentation are developed by the engineer. Experienced personnel are asked to use the documentation in these test situations and determine if the documentation satisfies their requirements.

TRAINING

Training must be given to maintenance personnel and operators before the system is accepted. The purpose of this training is two-fold. Most importantly, it provides the technical skills and proficiency required to operate and maintain the traffic control system. The training process also gives agency personnel an opportunity to be familiar with the overall system objectives, thus encouraging their acceptance of the system.

The training which is specified should reflect an appraisal of the actual needs and backgrounds of agency personnel. For example, if the maintenance staff are already familiar with the particular technology of a system component, the corresponding training should be limited to familiarization sessions on the actual unit provided. In a similar fashion, if software modifications will not be performed by agency staff, then only minimal software training (i.e., structure, coding, etc.) needs to be provided; except that this training should adequately instruct personnel on the organization of the data base and procedures for its updating and expansion. On the other hand, training should be extensive for equipment and technologies that are new to the agency staff. Training in the operation of the traffic control system is also very important.

Elaborate training can be expensive. Thus, only that training which is necessary to correct deficiencies in the capabilities of the operations and maintenance personnel should be specified. The specifications should also indicate the existing skill levels of the persons to be trained so that the training programs can be developed accordingly.

The training process is most successful when it is continuous -- consisting of both formal and informal elements. Formal training consists of classroom-style seminars and workshops. Informal training should be "hands-on" -- consisting of day-to-day interaction between the agency personnel and the contractor/systems manager throughout the implementation and start-up phases. The latter training is usually the best, and is gained by an active, aggressive involvement throughout the process.

Training and documentation should be specified to go hand-in-hand. For example, the operators manual should be used as the primary text during the training sessions on systems operation, and equipment manuals and related documentation should be extensively utilized during the training on system hardware maintenance. This approach will let agency personnel become familiar with the documentation, and will aid in identifying errors and deficiencies in the documentation so they can be corrected prior to final acceptance. Furthermore, the documentation should be submitted a sufficient time before training commences so that the personnel involved in the training sessions can review the information.

Other requirements that should be included in the training specifications include:

- Maximum number of persons to attend each formal training session.
- Minimum number of days for each training program (e.g., 5 days for controller training). It is also important to define what a day is (e.g., minimum of 6 hours).
- Contractor shall develop and supply all necessary manuals, displays, class notes, visual aids, and other instructional materials for the training program.
- Outline of lectures and demonstrations, and samples of all training materials shall be submitted to the agency for review some specified time period prior to their proposed use. Agency approval of these materials is required prior to the training courses being scheduled.

- Where training is to be conducted (e.g., local site designated by the engineer, or contractor's facilities). If at a contractor's facilities, define who is responsible for paying the transportation and subsistence costs of agency personnel.
- All training to be conducted during normal business hours of the agency and the training site.

MAINTENANCE ACTIVITIES

As previously noted, the enhanced monitoring and malfunction detection capabilities of computer-based traffic control system can require a higher and more responsive degree of maintenance. Additionally, there are usually more components to maintain with a system than without. The successful performance of any traffic control system is dependent on an effective maintenance management program.

The serious implications of inadequate maintenance are evident in several ways. Signal failures can result in accidents for which the operating agency may be held liable. Even the failure of a single component in a system may cause a degradation of system performance. Lack of maintenance can also drastically reduce equipment service life.

Hardware Maintenance

Hardware maintenance consists of preventive maintenance procedures required to keep the equipment in good working condition, and remedial maintenance to repair a known malfunction.

Preventive maintenance is particularly important for certain computer peripherals (e.g., cleaning). In terms of field equipment, however, Parsonson notes that modern solid-state equipment requires much less preventive maintenance than older electromechanical designs which involved more moving parts. He concludes that the emphasis of routine scheduled maintenance is no longer concerned with preventive measures; rather the emphasis is on inspection patrols and self detection methods to discover malfunctions, and on the subsequent checking to be certain that the faults have been corrected. (11)

Successful remedial maintenance, and preventive maintenance to some extent, is dependent on a number of factors, including:

- Time that a failure exists before it is reported.
- Response procedure (e.g., dispatching routine, response priorities, off-hours emergency response).
- Number of maintenance personnel and their respective skills and qualifications.
- Maintenance facilities -- spare parts, test equipment, vehicles.
- Hardware documentation.
- Recordkeeping of maintenance activities.

All of these elements must be considered during the system process and incorporated into the contract documents and maintenance management program as applicable.

Contract Maintenance

A perennial problem for many government agencies is recruiting, and then retaining, personnel who possess the skills necessary to maintain the sophisticated hardware associated with computer-based traffic control systems. Proper maintenance of systems can require salary schedules higher than normal maintenance or electrician rates; and agencies are often unable to pay these prevailing wages. Accordingly, some agencies have determined that the best practice is to use maintenance contracts. Contract maintenance often eliminates the need to hire additional staff and to stock specialized spare parts. It may also provide better cost control and accountability of maintenance activities.

Contract maintenance is used to some extent in nearly all traffic control systems. Maintenance of the computer and peripherals is a prime example. The contract is usually with the computer manufacturer and provides for both preventive and remedial maintenance, including parts and labor, at a fixed monthly fee. In general, normal weekday service is adequate, particularly if some form of backup system control is provided. Full, 24-hour computer maintenance service with quick response times is available, but at a greater cost.

Another form of contract maintenance that has been used successfully in traffic control systems is the repair of communications modems and interface units. These units can be mailed back to the manufacturer for repair on either a contract basis or at a unit cost. Leased communications networks (telephone, CATV) also involve a form of contract maintenance.

Currently, the need for contract maintenance is greatest where high-technology hardware (e.g., computers and communications modules) are involved. However, there are situations involving noncomputer-based equipment where contracting may be advantageous. The responsibility for overseeing and inspecting the work of the maintenance contractor and enforcing the specified response times, etc., remains with the agency. Sections of a representative maintenance agreement are provided in table 15.

Contract maintenance requires significant coordination on the part of the agency. The preparation of the maintenance agreements should also follow the guidelines for specification writing discussed in the previous chapter on design.

Software Maintenance

Software maintenance can not be overlooked in assessing the total system maintenance requirements. The computer programs are usually (and should be) provided as a complete, operating, tested and debugged package at the time of system acceptance. However, because of the multitude of different possible computation combinations and operational circumstances that will arise over time, these complex programs often reveal additional flaws, or bugs, during their first few years of operation. Additionally, as operators gain experience with the system, they may discover procedures that could be improved (i.e., made more efficient) or identify additional system features and reports which are desirable.

A full-time programmer on staff is seldom, if ever, required for today's computer-based traffic control systems. However, entering into a software maintenance agreement with the system supplier can be a worthwhile and cost-effective endeavor. Under this agreement, the supplier can correct any latent bugs and make minor enhancements based on the experience of the operators. This software maintenance can often be accomplished over a phone link and modem.

Unless an agency also plans to use the computer for in-house program development, the computer maintenance agreement should generally not include updates to the operating system software. If the traffic control system is to be used only for traffic control and will not be modified except for expansions within

Table 15. Sample maintenance agreement provisions.

- During the normal working week, the Agency analyzes the previous day's data and the current morning data. Should any malfunctions be found by this analysis, the Agency will, by 10:00 a.m., call by telephone the Contractor's radio room and report all malfunctions. The Contractor's radio dispatcher shall log this call and dispatch personnel to correct the malfunction. All reports of any malfunction in the system reported to the Contractor's dispatcher which are received by 10:00 a.m. shall be responded to and corrected during that working day. All action taken by the Contractor's personnel to correct the malfunctions shall be reported back to the Agency during the working day. All reports of any malfunction in the system reported to the Contractor's dispatcher which are received after 10:00 a.m. shall be responded to and corrected not later than the following working day.

- The Contractor shall submit to the Agency a printout of the previous half month's maintenance and service records. This printout shall include the following: route number and/or name, location, date, time malfunction call received, function of equipment calling received on, equipment model, date call was responded to, corrective action taken to make equipment operational, and date and time when all work was completed or removed equipment was replaced with original equipment.

- The Contractor shall, on the second (2nd) and fourth (4th) (name of day) of every month, or as approved by the Engineer, visit each intersection/ramp metering location and perform the following activities:

    - Verify proper operation and signal head aiming.
    - Relamp burnt-out bulbs.
    - Tighten cabinets/signals on foundations.
    - Lubricate doors and locks.
    - Check detector tuning.
    - Clean signs, lenses, and reflectors.

- The Agency shall report any malfunction in the system to the Contractor any time during the day or night. Contractor shall take immediate corrective action to safeguard the public and the installations at any time, day or night, when any system or any portion thereof becomes inoperative, or any unit of the system has been damaged from any cause whatsoever.

- The Contractor shall maintain in stock sufficient assorted components in order that all malfunctions from any cause whatsoever can be temporarily or permanently corrected and all defective or damaged components can be replaced.

Table 15. Sample maintenance agreement provisions (continued).

- In case of signal knockdown, the Contractor shall make emergency temporary repairs and permanent repairs to the installations. Unless specifically authorized by the Engineer, permanent repairs shall be completed not later than 8 hours following emergency temporary repairs and shall be continued without interruptions until completion. The Contractor shall submit to the Agency an itemized cost breakdown of all labor, material and equipment used in the replacement of knockdowns.

- Maintenance agreement terms include:

  - Maintain intersection/ramp control signal head (per month).
  - Maintain intersection/ramp metering control cabinet (per month).
  - Maintain loop detector (loop wire, amplifier, sawcut) (per month).
  - Furnish and install detector sensor unit (per unit).
  - Furnish and install communications cable (various sizes) (per lin ft).
  - Furnish and install conduits (various sizes) (per each).
  - Furnish and install cabinet (per installation).
  - Painting cabinets, signals, posts (per installation).

the initial configuration, then the operating system software should be "frozen" at the revision level existing at the time of system installation. While operating system updates are theoretically upward compatible, there have been instances where the traffic control applications software would not function properly (e.g., computer ran out of processing time or memory space) following the installation of an operating system revision.

OPERATION ACTIVITIES

There are significant differences between traffic signal systems and freeway surveillance systems in terms of their respective operational requirements. Most traffic signal systems have the capability of virtually unattended operation whereby signal timing and control is altered in accordance with predefined time-of-day/day-of-week schedules or by a traffic responsive algorithm. Manual intervention typically occurs only in response to congestion, incidents, special events, and maintenance problems; which may require the operator to implement special timing plans, change intersection timing parameters on a temporary basis, dispatch maintenance personnel for repair of a component in response to a malfunction alarm, or return a previously malfunctioning controller to system control, etc.

The proper staffing periods for a traffic signal system can be determined only by experience with the system's operation over a reasonable period of time. Some signal systems are attended from just prior to the beginning of the morning peak to just past the end of the evening peak, while others are attended during the peaks only. There are also traffic signal systems -- some of which are relatively large -- that are not attended on any sort of regular basis.

Freeway surveillance and control systems typically require continuous, dedicated operator monitoring and intervention. The duties of the system operators may include:

- Monitor system peripherals (CCTV, graphics display, map display, CRT reports) and analyze traffic flow status.
- Operate variable message signs.
- Initiate and monitor ramp metering.
- Report incidents to police and other emergency services.
- Report malfunctions to maintenance personnel.

- Provide traffic information to the media.
- Keep logs of system operation and incidents.

Operators of a freeway system must be able to devote full attention to the system during the peak traffic periods when incidents are most likely to occur. During off-peak periods, other related tasks are possible (e.g., data collection, studies, reports, etc.); but the operator must be in a position to immediately devote full attention to the system when an incident occurs. It is noted that a few freeway systems use only college students -- full-time co-ops or part-time -- as system operators.

In addition to the necessary functions of system interface and intervention, there are also several basic tasks associated with traffic control systems -- both traffic signal and freeway surveillance -- which should be performed to assure continuity of operation and to retrieve archival data, including:

- Maintaining a daily control log, including a checklist of items and tasks that must be performed by each operator. System functions and component failures are also recorded in the log.
- Retaining tape copy of daily summary reports.
- Retaining Retain hard copy of all failures, preemption records, sequential system operation record, etc. for at least 1 year.
- Backing up complete system data base on tape, at least on a monthly basis, and retain for 3 months.
- Preventive maintenance of computer hardware -- running diagnostics and coordinating the computer maintenance contract.
- Documentation control (i.e., keeping changes up-to-date).
- System expansion activities (e.g., design, installation assistance, develop and input additional data base).
- Updating system timing.

Signal Timing

The last task -- updating the system timing -- is perhaps the most important activity in the operation of a computerized traffic control system. Wagner suggests biannual updates, and reports that optimization of timing plans alone (i.e., no changes in hardware) can result in a 12 percent improvement in travel time.(12) Robertson indicates that old timing plans cause an extra 4 percent of delay for each year of their age.(11) In general, signal timing updates are needed more frequently in outer suburban areas, where land use and traffic patterns are changing at a rapid pace, than in mature, fully developed urban locations. The actual frequency at which timing plans should be updated is dependent on the rate-of-change of traffic conditions within the signal system, which is a function of land use and roadway changes. As such, traffic volumes should be monitored over time. It is also necessary to drive the system occasionally to visually observe and evaluate the effectiveness of the control strategies.

Updating system timing also applies to freeway control and surveillance systems. Control strategies should be periodically reevaluated and modified as required, including the time when ramp meters are turned on and off, algorithms for selecting the metering rates, and the meter rates themselves.

The function of timing plan maintenance includes the following activities:

- Identifying need for new timing plans.
- Collecting data.
- Developing revised timing plan parameters (e.g., TRANSYT 7-F or similar program).
- Reviewing output (e.g., time-space diagrams) and adjust as required.
- Preparing timing plans in the appropriate data base format and input to the system.
- Evaluating new timing plans (field evaluation) and fine tuning.

System timing does require a significant amount of effort. For example, a 1986 California study estimates the cost to be $1,100 per signal for the development of three new timing plans.(1) FHWA found that it takes 40 hours of labor per signal to develop three new timing plans.(8) Yet, updating the system timing is one of the most cost-effective activities an agency can undertake. Recent studies have determined that the cost-benefit ratio of signal timing (in fuel benefits alone) ranges from 10 : 1 to 15 : 1.

Nevertheless, very few agencies keep their system timing plans up-to-date other than to adjust individual signal timings when equipment fails or when complaint-generating operating problems occur. The reasons for this dismal record are a combination of the significant costs associated with signal timing; staff which lacks sufficient time and/or the necessary skills to use automated timing methods such as TRANSYT; and the fact that system timing does not generate much citizen support -- the aggregate benefits are significant, but it is unlikely that the average motorist who saves less than a dollar a week in fuel costs will notice.

There are ways in which these problems can be circumvented:

- Public education of the benefits of up-to-date system timing.
- Using consultant services for developing and inputting updated system timings. This eliminates the problem of insufficient staff time and qualifications, but still requires budget commitments.
- Requiring developers to fund new timing plans. Considering that major new developments are a primary factor in traffic changes which render existing timings inadequate, this appears reasonable. However there may be some institutional problems with this approach.
- Using advanced traffic control schemes, such as 1.5 and 2nd generation control, which automatically update timing plans. However, as previously discussed, the effectiveness of these strategies depends on increased detector maintenance.

The critical importance of updating system timing plans cannot be underestimated. A system can never be completely successful if it is using timing plans and control strategies that aren't suited to current traffic conditions.

APPENDIX - BASIC TECHNICAL REFERENCES FOR TRAFFIC CONTROL SYSTEMS

TRAFFIC CONTROL SYSTEMS HANDBOOK

The purpose of the handbook is to document traffic control concepts, principles of analysis and design of traffic surveillance and control systems, and to present an insight into the most advanced available technology. This handbook is to be used as an aid in the planning, design, and implementation of traffic surveillance and control systems on both freeways and urban streets.

Available from:

Institute of Transportation Engineers
Suite 410, Publications Department
525 School Street, SW
Washington, D.C. 20024

FHWA Report # FHWA-IP-85-11
NTIS PB # 86 131760/AS

COMMUNICATIONS IN TRAFFIC CONTROL SYSTEMS

This publication discusses several communication technologies and their application in computer-based traffic control systems. Communications media which are addressed include twisted-pair cable, leased telephone, coaxial, leased CATV, fiber optics, microwave, optical infrared, and radio. Guidelines for analyzing and selecting the optimum technology for a particular system are also presented. The information can be used to design and install efficient communication subsystems for traffic control applications while minimizing the associated costs and risks.

Available from:

HSR-10
Federal Highway Administration
6300 Georgetown Pike
McLean, Virginia 22101-2296
703-285-2408

FHWA Report # FHWA-RD-88-011- Volume I:Executive Summary
FHWA Report # FHWA-RD-88-012- Volume II:Final Report

TRAFFIC CONTROL DEVICES HANDBOOK (PART IV SIGNALS)

The Traffic Control Devices Handbook (TCDH) offers guidelines for implementing the standards and applications contained in the MUTCD. The Handbook provides information related to the fundamental concepts of traffic regulation and control, traffic control devices, current application practices, and promising traffic engineering techniques of the future. The material in the handbook reflects the experience of State, county, and city agencies and also reflects recent research results.

Available from:

Superintendent of Documents
Government Printing Office
Washington, D.C. 20402

Stock Number 050-001-00270-1

MANUAL OF TRAFFIC SIGNAL DESIGN

This ITE publication presents the fundamental concepts and standard practices related to traffic signal design commensurate with the state-of-the-art. While it is recognized that signal design procedures may vary widely among various jurisdictions, this manual sets forth the techniques and procedures that may be applied in developing clearly defined plans and specifications. Much of the information contained in this manual represents the composite experience and effective practices of many agencies. It also incorporates and, in some cases, enlarges upon accepted procedures as documented in other standard references.

Available from:

Institute of Transportation Engineers
Suite 410, Publications Department
525 School Street, SW
Washington, D.C. 20024

CATALOG OF FUNCTIONS FOR COMPUTER-BASED TRAFFIC SIGNAL SYSTEMS

This report includes a description of a "Basic" computer-based traffic signal system plus a listing and description of options which can be added. The report contains a description of the Basic system, plus options; traffic performance and utility considerations associated with each option; and a cross-reference between the catalog of functions and the functional specifications.

The standardization of the functional requirements of the Basic system, and of the functional requirements for additional options, will assist planners and users in the functional design of these systems, as well as assist designers in the design of hardware and software components.

Available from:

The National Technical Information Service
5285 Port Royal Road
Springfield, Virginia 22161

FHWA Report # FHWA/RD-85/078
NTIS PB # 86 180486/AS

UTCS FUNCTIONAL HARDWARE SPECIFICATION HANDBOOK

The Handbook includes specifications for a UTCS-Enhanced Signal System, including controllers, detectors, circuit protection, communication equipment, computers and peripherals, control and display devices, traffic application software, operating system software, and the interfaces between system elements. Information is provided to help the designer make informed decisions as to what hardware is necessary for a system. Also included, are specifications for testing, training, and documentation.

Available from:

The National Technical Information Service
5285 Port Royal Road
Springfield, Virginia 22161

FHWA Report # FHWA-IP-86-13
NTIS PB # 87 13032

TRAFFIC DETECTOR HANDBOOK

This handbook provides information to enable the practicing traffic engineers and technicians to design, install, operate, and maintain traffic detectors. The document presents information for three most widely used traffic detectors; the magnetic detectors; the magnetometer; and the inductive loop detector.

Available from:

The National Technical Information Service
5285 Port Royal Road
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FHWA Report # FHWA-IP-85-1;
NTIS PB # 86 149226/AS -- Handbook
FHWA Report # FHWA-IP-85-2;
NTIS PB # 86 149234/AS -- Field Manual

MANAGEMENT OF TRAFFIC CONTROL MAINTENANCE

This synthesis describes the management measures that are being applied by a variety of agencies with respect to the maintenance of traffic signal equipment and systems. Individual operations that have been used with evident success, including handling of maintenance repairs, routine inspection and maintenance of parts, furnishing and stocking of repair shops, attraction and retention of personnel and record keeping and documentation, are described and analyzed.

Available from:

Transportation Research Board
National Academy of Sciences
2101 Constitution Ave., NW
Washington, D.C. 20418

LIGHTNING PROTECTION HARDWARE AND TECHNIQUES FOR ELECTRONIC TRAFFIC CONTROL EQUIPMENT

This handbook provides a reference source suitable for understanding the phenomena of lightning-induced damage and minimizing those effects. The document also includes information on the identification of approaches for reducing the susceptibility of traffic control electronics to conducted electrical noise and development of a synthesis of recommended practices for electrical noise control in terms of hardware components, techniques, methods, and procedures.

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FHWA Report # FHWA/RD-86/073
NTIS PB # 86 169620/AS

NATIONAL ELECTRICAL MANUFACTURERS ASSOCIATION STANDARDS PUBLICATION NO. TS1-1983 TRAFFIC CONTROL SYSTEMS

This Standard Publication covers widely used traffic signaling systems which are used to facilitate and expedite the safe flow of pedestrian and vehicular traffic. The Standard defines traffic signal equipment available from many manufacturers which provides interchangeability at the plug level. It is useful in specifications for such equipment.

Available from:

National Electrical Manufacturers Association
2101 L Street, NW
Washington, D.C. 20037

UTCS - EXTENDED AND ENHANCED SOFTWARE AND DOCUMENTATION

The Urban Traffic Control Systems (UTCS) 1st Generation Extended and Enhanced Software are FORTRAN software packages which can be used to provide on-line control of traffic signals in a computerized signal system. The software can be used with a variety of computer, controllers, and communications hardware. It can control multiphase fully actuated, semi-actuated, and fixed-time controllers. The software can accommodate 255 controllers and 255 detectors. The Extended version uses a menu-driven interface. The Enhanced version is based on the Extended version, but uses an operation interface language and incorporates a number of additional features.

Available from:

HTO - 23
Federal Highway Administration
Washington D.C. 20590
202-366-2186

INSPECTORS MANUAL FOR TRAFFIC SIGNAL CONSTRUCTION

The objective of this manual is to provide engineers and inspectors with the information necessary to assure successful installation and completion of traffic signals and other highway electrical projects in compliance with the contract documents. The manual addresses preconstruction activities, job records, construction activities and the potential problem areas associated with each, and final cleanup and inspection. The manual was prepared by the Texas Department of Highways and Public Transportation.

Available from:

Texas Transportation Institute
Texas A & M University System
College Station, Texas 77843-3135

SIGNAL TIMING OPTIMIZATION AND SIMULATION SOFTWARE

Floppy disks containing a microcomputer version for the IBM-PC (and compatible), and the associated manuals and documentation are available from the Center for Microcomputers in Transportation (McTrans). Software programs include:

- TRANSYT-7F
- PASSER II
- SIGOP III
- NETSIM
- SOAP
- Related utility packages

Available from:

McTrans Center
University of Florida
512 Weil Hall
Gainesville, Florida 32611
904-392-0378

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