National Cooperative Highway Research Program

NCHRP Synthesis 245

Traffic Signal Control Systems Maintenance Management Practices

A Synthesis of Highway Practice

Transportation Research Board
National Research Council

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Traffic Signal Control Systems Maintenance Management Practices

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PREFACE

A vast storehouse of information exists on nearly every subject of concern to highway administrators and engineers. Much of this information has resulted from both research and the successful application of solutions to the problems faced by practitioners in their daily work. Because previously there has been no systematic means for compiling such useful information and making it available to the entire community, the American Association of State Highway and Transportation Officials has, through the mechanism of the National Cooperative Highway Research Program, authorized the Transportation Research Board to undertake a continuing project to search out and synthesize useful knowledge from all available sources and to prepare documented reports on current practices in the subject areas of concern.

This synthesis series reports on various practices, making specific recommendations where appropriate but without the detailed directions usually found in handbooks or design manuals. Nonetheless, these documents can serve similar purposes, for each is a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems. The extent to which these reports are useful will be tempered by the user's knowledge and experience in the particular problem area.

FOREWORD

By Staff Transportation Research Board

This synthesis will be of interest to traffic control systems managers and designers, maintenance managers and staff, communications managers and staff, and others who are responsible for the effective functioning of traffic signal control systems at the state, district, or local level. It will also be of interest to consultants and suppliers of traffic signal systems. It presents information on the current practices of state and local transportation agencies with regard to the maintenance management practices for traffic signal control systems.

Administrators, engineers, and researchers are continually faced with highway problems on which much information exists, either in the form of reports or in terms of undocumented experience and practice. Unfortunately, this information often is scattered and unevaluated and, as a consequence, in seeking solutions, full information on what has been learned about a problem frequently is not assembled. Costly research findings may go unused, valuable experience may be overlooked, and full consideration may not be given to available practices for solving or alleviating the problem. In an effort to correct this situation, a continuing NCHRP project, carried out by the Transportation Research Board as the research agency, has the objective of reporting on common highway problems and synthesizing available information. The synthesis reports from this endeavor constitute an NCHRP publication series in which various forms of relevant information are assembled into single, concise documents pertaining to specific highway problems or sets of closely related problems.

A previous NCHRP Synthesis, No. 114 (1984), examined the state of the practice with regard to traffic signal maintenance management. This synthesis reexamines current traffic signal control maintenance practices in light of the extensive use of solid state equipment, PCs, integrated systems and other advanced technologies, such as ITS

(intelligent transportation systems). This report of the Transportation Research Board discusses the current technologies and the maintenance concerns related to both hardware and software systems. It also presents information on traffic signal systems maintenance organizations and staff, maintenance programming and scheduling, ancillary equipment and repair facilities, cost of maintenance and funding sources, and management strategies.

To develop this synthesis in a comprehensive manner and to ensure inclusion of significant knowledge, the Board analyzed available information assembled from numerous sources, including a large number of state highway and transportation departments. A topic panel of experts in the subject area was established to guide the research in organizing and evaluating the collected data, and to review the final synthesis report.

This synthesis is an immediately useful document that records the practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As the processes of advancement continue, new knowledge can be expected to be added to that now at hand.

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TRAFFIC SIGNAL CONTROL SYSTEMS MAINTENANCE MANAGEMENT PRACTICES

SUMMARY

Traffic control systems are expected to continue to grow in size and in complexity, even as resources continue to decrease. Many transportation agencies currently believe that they are doing a fair to poor job of maintaining their present systems. How, then, will agencies be able to improve the maintenance of their systems while doing more with less? One way is to use the best maintenance management systems available that will suit their needs. This synthesis has been prepared to present the state of the practice in maintenance management of traffic signal control systems to assist agencies in improving their own systems.

Maintenance management practices vary widely among transportation agencies. Most agencies (50 percent of those answering a survey of 152 transportation agencies) use a paper filing system, even though there are many types of software available for management, scheduling, administration, inventory control, and record keeping. It is expected that more agencies than the 18 percent that reported using computerized system will do so in the future.

Maintenance is divided into three types: response, preventive, and design modification. Response maintenance is performed on an as-needed basis to repair a malfunction and is practiced by all agencies with varying response times. Preventive maintenance is performed on a regularly scheduled basis using a set of procedures to preserve the intended working condition of the traffic control system. Most, but not all, agencies perform this type of maintenance, which represents about one-third of their overall program. Design modification is used to correct a recurring problem, to accommodate changes in prevailing traffic or physical conditions, or to update installations to the current state of the practice. Approximately 75 percent of the agencies surveyed reported design modification activities, which accounted for about one-sixth of their traffic signal control system maintenance program.

Most agencies do not share resources such as personnel, devices, equipment, responsibility, or authority with other agencies. They also most often use the low-bid process for the procurement of equipment, parts, and services. In some cases, a prequalifications process is added.

The number of maintenance personnel has changed over the years as a result of the evolution of traffic control equipment from mechanical to electronic devices. For those agencies that maintain their own systems, the survey revealed that the number of maintenance personnel generally increased with an increase in population at a rate of approximately 2.6 employees per 100,000 persons for city agencies and a rate of 2.3 for state agencies. No definable rates could be determined for agencies that contract all or part of their maintenance.

County agencies appeared to have larger budgets for equipment than states and cities, while state agencies appear to have the largest budgets for personnel and spare parts. Cities have the highest budget for contractor services. The source of budget funds is local and state taxes and gas taxes. The mix of taxes varies by government level and is expected to change in the future.

Tools are available to improve the maintenance management of traffic control systems to help agencies cope with an increase in the system size and components while facing reduced resources. The information in this synthesis can help agencies to understand these tools and improve their programs.

CHAPTER ONE

INTRODUCTION

BACKGROUND

Maintenance is defined as the act of preserving a particular state. With respect to traffic control systems, it is the act of keeping the systems operating as they were intended to operate. Management is the skillful use of available resources to achieve a goal. Maintenance management of traffic signal control systems is the skillful and efficient use of resources to keep the systems operating as intended. It is important to remember the distinction because this report deals with the management of maintenance not the act of maintenance.

This synthesis updates NCHRP Synthesis 114: *Management of Traffic Signal Maintenance (1),* which focused on the transition in maintenance requirements and practices as hardware evolved from electromechanical to solid-state design. Since its publication in 1984, many changes have occurred in the technology and maintenance of traffic signal systems. Maintenance management practices have, therefore, also changed. This synthesis examines current traffic signal control maintenance management practices in light of the extensive use of solid-state equipment, personal computers, and integrated systems.

To determine the current state of traffic signal system maintenance management, an extensive literature search was performed and a survey of state, county, and city agencies in the United States; of provincial and city agencies in Canada; and of selected manufacturers was conducted. The survey instrument was mailed to representatives in 152 state, city, county, and Canadian province agencies. The state representatives were the traffic engineers for the state departments of transportation. At least one city or county was chosen from each state, based on population. Of the 152 surveys mailed, 89 responses were received, a response rate of 59 percent. Fifty city and county agencies out of 93 answered the questionnaire, representing a 54 percent response. The highest response rate (74 percent), was from the 37 states responding out of 50. Three of nine Canadian provinces replied, a rate of 33 percent.

Of the 90 individuals who responded to the survey, 77 indicated that they are responsible for maintaining the traffic signal control systems in their jurisdictions. All of the survey results presented in this synthesis are based on a percentage of the 77 respondents responsible for maintenance in their jurisdictions. Of these 77 respondents, 38 are city agencies, seven are counties, 30 are states, and two Canadian provinces.

The survey form is in Appendix A; the responses are summarized in Appendix B, which provides general information about, and the results from, the survey, including the number, type, and size of agencies responding. Relevant results and statistics are provided. Agencies nationwide were asked to provide information on their maintenance schedule, staffing, management practices and how they rate their ability to maintain their current system. This synthesis, written with maintenance managers and their supervisors in mind, presents the results of the literature review and the survey.

Report Structure

Chapter 1 discusses traffic signals and their maintenance in a historical context. Chapter 2 briefly describes the systems and their components to indicate what must be maintained. In Chapter 3, information is provided on the current state of the practice with respect to traffic signal systems maintenance. Chapter 4 presents conclusions drawn from the previous three parts. Appendix C contains a preventive maintenance check list. Appendix D contains a summary of procurement methods identified by the survey. Appendix E provides the references for all works cited in the appendices.

Historical Perspective

Historically, public agencies have experienced difficulties in maintaining their traffic signal control systems for many reasons: funding issues, lack of proper training, poor design decisions and construction, poor installation, ineffective management of available resources and personnel, and the challenge for "traditional" management structures to make appropriate decisions as technology rapidly changes. Many steps have been taken to improve the management of traffic signal system maintenance.

Since the last synthesis on traffic signal maintenance management, new types of technologies have been implemented to improve the state of traffic signal control. Today's systems incorporate communications technologies, computers, surveillance equipment (such as closed circuit television (CCTV), detectors, and many other elements. In addition, intelligent transportation systems (ITS) have been developed and are being deployed throughout the country for surveillance and control of traffic signal systems. As systems become larger and more complex to accommodate increasing traffic demands, more intensive maintenance, higher funding levels, and more employees with higher skill levels are required. This issue can be offset by the use of computers that permit the accumulation of maintenance information into data bases from which information can be selected and processed to assist in making cost-effective management decisions.

Magnitude Of The Current Problem

With an increasing number of traffic signal systems, and therefore an increasing number of signalized intersections, maintenance management has become an important issue.

Public agencies are responsible for systems that are growing in size and complexity while staffing and resources are shrinking. Thus, it becomes increasingly difficult to provide proper maintenance for equipment within their jurisdictions.

According to a recent survey conducted by the Institute of Transportation Engineers (ITE) (*2*),

- The number of signals that are part of coordinated signal systems is expected to increase by 28 percent over current levels by the year 2000.
- Transportation agencies reported a 20 to 25 percent shortfall in funding and personnel needed to effectively operate and maintain present traffic control systems.
- Forty-four percent of responding agencies rated their ability to operate and maintain existing systems as fair or poor.

These results emphasize the need for strong management practices to maintain current systems that are growing rapidly. The net effect will be continuing to do more with less. Poor maintenance management practices will inhibit the growth of traffic signal control systems leading to growing traffic congestion, decreased safety, declining air quality, and less mobility.

TYPES OF MAINTENANCE

There are three main types of maintenance:

- Preventive,
- Response, and
- Design modification.

Each of these types plays an important role in the overall maintenance of a system. This section defines each of these three types of maintenance and provides examples of activities.

Preventive Maintenance

Preventive maintenance is performed on a regularly scheduled basis using a set of procedures to preserve the intended working condition of the traffic signal system. Periodic maintenance can prolong the life of the system and usually includes inspection, cleaning, replacement, and record keeping. These activities occur based on each component's function and rated service life (*3*).

The objective of preventive maintenance is to ensure that the system operates properly. Defective equipment can be replaced or repaired before failure occurs reducing the need for responsive maintenance resulting in reduced road user costs, and liability exposure (*1*). Education and research have led to the acknowledgment that preventive measures and changes in design and operations are just as important as response or emergency measures.

ITE has published a recommended checklist for the preventive maintenance of traffic signal systems. This list, contained in Appendix C (*4*), includes a recommended interval in months or years for items in various categories.

Response Maintenance

Response maintenance is performed on an as-needed basis. Also known as emergency maintenance, it is required when equipment breaks down or malfunctions. On notification, the responsible agency is expected to dispatch a repair service team to secure the site, diagnose the problem, perform the repairs, and record their activities as quickly as possible. Many agencies set goals or have a schedule for each of these activities based on the types of failures and resources available for the repairs (*5*).

Although ITS can make it possible for systems to monitor many functions and notify the proper managers automatically, many agencies still rely on traditional notification practices. These practices include notification through internal sources (the operating agency), external sources (the media, police, etc.), and the general public (*4*).

After the agency has been notified of an equipment break down, a repair team is dispatched. The team secures the site so repairs can be made safely. The first step is to diagnose the problem. After the problem has been identified, the faulty equipment is replaced and then repaired in the shop or by the manufacturer to ensure that traffic conditions are returned to normal as quickly as possible. Performing repairs in the shop rather than in the field improves the quality of the repair and enhances proper maintenance documentation (*4*). In some instances, a temporary repair must be made because replacement parts are unavailable or the damage cannot be repaired immediately. The temporary repair may use temporary control devices and or timing changes. Jurisdictions may allow different practices for public agencies or private contractors.

All activities performed on request should be clearly and concisely documented for future reference. Computerized records can reduce the time required for record keeping and can be retrieved quickly and easily, even from remote locations.

Design Modification

Design modification is usually invoked to correct a recurring problem, to accommodate changes in prevailing traffic or physical conditions, or to update installations to the current state of the practice. This type of maintenance is a change in the approved design and operations of an existing traffic signal system. Examples of design modifications include (*4*):

- Addition or removal of a phase,
- Changes in signal displays, configurations or locations,
- Detector changes,
- Revisions to related signs and pavement markings,
- Equipment revisions or upgrading (hardware and software), and
- Timing changes.

Design modification may be required to address preventive and responsive maintenance issues such as frequent lamp failure resulting from poor quality or water leakage, signal head visor damage, signal head alignment, signal head mounting

heights, and traffic signal hardware knockdowns. These problems usually are caused by design deficiencies and can be corrected. ITE recommends review of the design and operation of signalized intersections every 2 to 3 years. Intersections should be inspected for conformance with the approved plan, state-of-the-art design standards and features, and compatibility with prevailing traffic demands and physical conditions (*4*).

CONSEQUENCES OF FAULTY MAINTENANCE

Consequences of system failures and malfunctions caused by design, installation, maintenance, and operational deficiencies can be categorized into five major areas:

- Increased motorist costs,
- Increased maintenance,
- Increased accidents and liability,
- Poor air quality, and
- Poor public image.

Increased Motorist Costs

Signal control system malfunctions may create unnecessary stops and delays that waste motorists' time and fuel and increase pollutant emissions. Road-user savings alone provide sufficient cost justification for proper signal maintenance—the savings in time and fuel to motorists can exceed the cost of a good signal maintenance program. Traffic signal phasing and timing to provide smooth progression through adjacent signalized intersections is a technique that can mitigate this consequence.

Increased Maintenance

Faulty control system equipment requires maintenance expenditures to repair or replace parts, and often shortens the useful life of the equipment. Inadequate design attention to future maintenance requirements, inadequate inspection during installation, and improper maintenance practices may lead to unnecessary failures or malfunctions, increasing staff time, replacement part costs, and inventory requirements.

Increased Accidents and Liability

Faulty installations and improper or negligent maintenance can increase accident rates and may subject responsible agencies and their personnel to liability claims. Lawsuits based on alleged negligence in design, construction, inspection, and maintenance by personnel have increased in recent years. These lawsuits have resulted in greater expenditures for liability insurance premiums and for settlements awarded to claimants. Cases in which clearance intervals did not conform to the *Manual on Uniform Traffic Control Devices*, no signal indications were provided in one direction, and poles and push buttons were not grounded have resulted in findings of liability and large settlements. The exposed electrical cable in Figure 1 is an example of poor risk management.

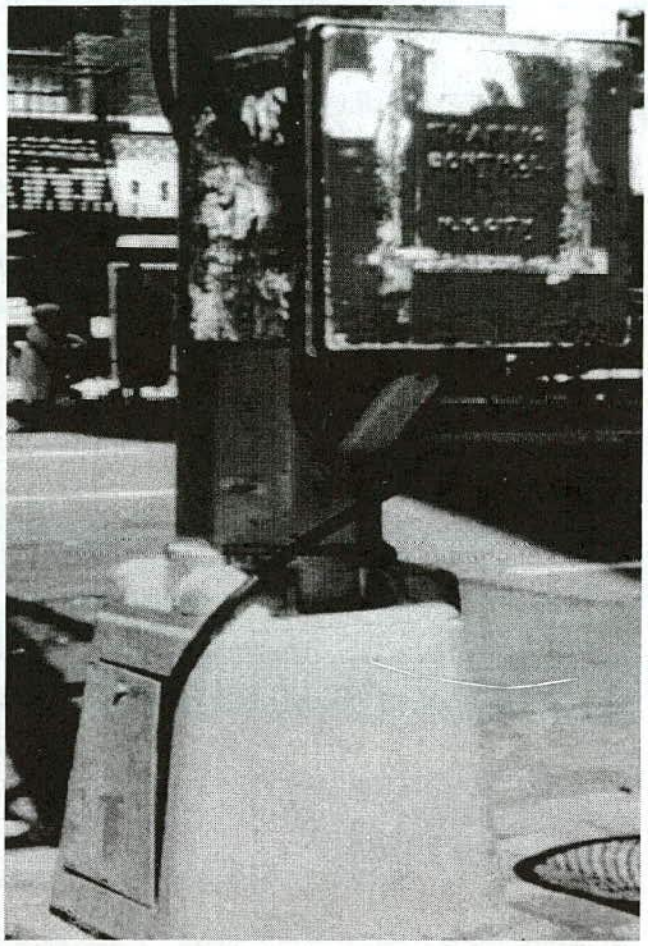

FIGURE 1 Controller cabinet requiring maintenance of an exposed electrical cable.

Poor Air Quality

Faulty control system equipment and improper or insufficient maintenance can affect traffic flow and possibly degrade air quality, potentially causing the responsible agency problems in meeting air quality goals established by the Clean Air Act and resulting in increased fuel costs and air pollutant emissions. Unnecessary vehicle stops contribute significantly to these consequences. Emphasis has been placed in recent years on establishing systems to improve air quality either locally or regionally. Nonconformance with federal regulations such as the Clean Air Act could affect federal funding of current or future projects.

Poor Public Image

The public usually has no perception of traffic control devices unless the devices malfunction because of nonoperability

or degradation, or if motorists are consistently delayed at a traffic signal with no traffic on the cross street. Examples of the former consequence are signal lamp burn-outs; changeable message signs (CMS) that are not readable, current, or properly displayed; highway advisory radio (HAR) that is not understandable; excessive delay due to nonfunctioning detection or coordination; and radio traffic news that recommends an alternate route that has not been optimized by the responsible agency. Poor maintenance may evoke a negative public image (Figure 2).

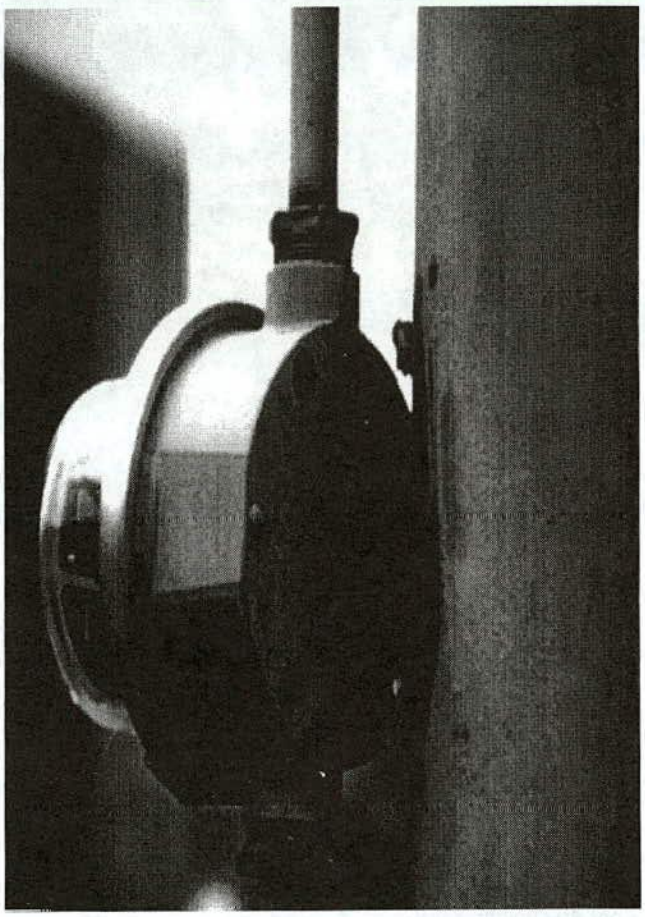

FIGURE 2 A meter base detached from the pole is an example of poor maintenance that may result in electrical failure and a negative public image.

The consequences of faulty maintenance—increases in motorist costs, maintenance, accidents, and liability, poor air quality, and tarnished public image—combine to reinforce the importance of traffic control system maintenance. Failures or malfunctions will sometimes occur; however, good maintenance practices can significantly reduce adverse consequences to public agencies and their communities, and improve customer satisfaction.

MAINTENANCE MANAGEMENT PRACTICES

Aggressive and creative management of maintenance activities can ease the burden that many agencies face in maintaining their traffic control systems. Management activities such as scheduling, budgeting, staffing, and record keeping are essential to properly maintain the growing number of systems and advancing technology and all are interrelated. This section describes these maintenance management practices.

Scheduling

Some types of maintenance, such as preventive maintenance, should be performed on a regularly scheduled basis to keep the system operating properly and provide for the most effective use of resources. Developing, tracking, and adjusting a maintenance schedule requires management of activities. The schedules should be developed based on system needs, agency personnel, and funding and be adjusted according to changes in these criteria. Other types of maintenance, such as response maintenance, cannot be scheduled in the same manner However, based on past experience and trends, the amount of time, staff, and budget required can be estimated and it is necessary to allow for emergencies. It should be noted that a schedule should reflect factors such as climate. For example, an area that is prone to hurricanes may experience more knockdowns, therefore requiring more maintenance, than an area that rarely has hurricane activity. Available personnel time must allow resources for design modification, for a signal system can be efficient only if it is responsive to traffic demands.

There are no universal guides for determining the proportion of the yearly maintenance budget for each type of maintenance because this depends on many factors, such as the type and age of equipment, and the experience and expertise of the maintenance personnel. The proportions are system-dependent and are reactive to each other. For example, experience at the City of Los Angeles Department of Transportation indicated that insufficient time was allocated to preventive maintenance, resulting in an ever-increasing demand for response maintenance. The end result was too little time for preventive maintenance and the overall maintenance effort was larger than would have been required with an adequate level of preventive maintenance. This situation has since been remedied.

Budgeting

Funding is crucial to the proper maintenance of any system. It determines the types of equipment procured and the number of staff hired. Budgeting available funding is important to providing adequate service to an agency's jurisdiction. It is not always an easy task since it involves a balance and distribution of available funds, which are not always in cash. It also deals with systems, which by their nature, should be transparent to the decision makers.

Personnel and Staffing

An adequate number of well-trained staff is important for the proper maintenance of a system. Personnel should be

properly trained to match their responsibilities so they can fill an assigned role within an organizational structure. The number of personnel employed should be adequate to fulfill the maintenance needs of a system and is usually dependent on the size of the system and the scope and skill level of each employee classification in the organization (*2*).

Record Keeping

Record keeping to track schedules, budgets, equipment, and staff performance is important to the management of maintenance activities. Records provide a reference for future problems and can be important to liability issues. There are a number of philosophies on record keeping. At one end of the spectrum are those who want to keep only the data that are actually used to manage the performance of the system. At the other end are those who want to keep all data gathered for an indefinite period of time. A variety of forms, ledgers, and logs are presently used. The following records are recommended in the *Traffic Systems Installation, Maintenance and Operations Manual* planned for publication by ITE in 1997 (*6*):

> Master Record—A master log of all service calls listing the date, type of maintenance performed, and signature(s) of the maintenance personnel performing the work. Should include design-modification maintenance.
>
> Preventive Maintenance Record—A log for each preventive maintenance service call of the date, tasks performed, and signature(s) of the maintenance personnel performing the work.
>
> Preventive Maintenance Problem Record—A record of problems or potential problems identified (if any), corrective action taken, and follow-up inspection, including date(s) and signature(s) of the maintenance personnel performing the work.
>
> Response Repair Log-on Record—A log recording the location, date, time, caller, receiver and nature of complaint received; maintenance personnel and time dispatched; trouble found and time cleared.
>
> Response Maintenance Repair Record—A complete record for each call of the problem, notification details, prevailing conditions, work performed, parts replaced or repaired, time and condition on departure, and signature of the responsible repair person and supervisor.

Each of these logs or records can be maintained on paper or in computer files or data bases on a variety of software available from various computer vendors and software manufacturers. Signature requirements can be accomplished by using personnel codes. With the increase in office microcomputers, there has been an increase in the use of computerized record keeping. In some cases, paper records have been eliminated and field personnel use laptop computers and transfer their files to the office computer system on a daily basis. Computer systems provide the capability to sort, select, tabulate, and display data in a format to enhance maintenance decisions, reduce wasted resources, and ease the record-keeping burden.

Signal Timing Charts

Signal timing charts are another form of maintenance management. Signal timing charts, prepared by the traffic engineer, are best kept in both the signal controller cabinet and in the operations office. The charts are used by signal mechanics and other maintenance personnel to verify, and sometimes, adjust the signal timings at an intersection. Any changes to the timing plans are noted and a copy is sent to the operations office. A computerized data base is considered essential by many agencies with large systems.

Manuals and As-Built Plans

Equipment manuals can be an invaluable tool for maintenance personnel. Copies of manuals should be available in the field, and in the operations or maintenance office for quick reference.

As-built plans should always be available in the controller cabinets and in the operations or maintenance office. Any design-modifications should be noted on the as-built plans. Unfortunately, in many cases, the as-built plans are kept but are not updated. This could adversely affect the efficiency of future maintenance or the design of reconstruction or modification. Some governmental agencies may require additional records. For example, California mandates keeping up-to-date as-built plans for substructure markouts.

Computer systems now provide the opportunity to develop, store, revise, and retrieve plans as part of a computer-aided drafting (CAD) system.

A brief description of traffic signal control systems and their components that need to be maintained are presented in chapters 2 and 3. Chapters 4 through 8 present the current state of the practice with respect to traffic signal control systems maintenance. Conclusions are contained in chapter 9. The appendices contain useful information on the survey form and the agencies that responded, a preventive maintenance checklist, procurement processes received from survey respondents, and references used in the appendices.

CHAPTER TWO

TRAFFIC SIGNAL CONTROL SYSTEMS

There are two main types of traffic signal control systems: centralized systems and decentralized systems. This chapter describes both types and the various system components of each.

CENTRALIZED CONTROL SYSTEMS

Centralized traffic signal control systems use one computer for a network, or system of signals. The central computer sends commands to each of the signals in the system and, in more advanced systems, receives information from detectors and other surveillance equipment. Some of the characteristics of a centralized control system are:

- Second-by-second, real-time monitoring (*7*)
- One level of computation occurs prior to signals reaching the field controller (*8*)
- One communications protocol and one data rate exist between the control center and the field controllers (*8*).

Figure 3 illustrates a centralized control system architecture.

DECENTRALIZED CONTROL SYSTEMS

In decentralized traffic signal control systems, more computing is done in the field, less information is sent back to a central computer, and less communication is required (*9*). With this type of system the probability of total system failure is small. In addition, the computing burden is not concentrated on one machine. These types of systems can also use time-based controllers that receive settings by radio communications from the central controller, with no wire interconnections. Other versions of decentralized systems perform areawide traffic responsive control functions based on field detector data at the central control computer. A closed loop system is a decentralized system. Some of the characteristics of a distributed control system include (*8*):

- Multiple levels of computation in the field
- Data rate changes between the control center and field controller.

Figure 4 illustrates a decentralized system configuration. The distributed signal control system illustrated in Figure 4 has two levels. Level 1 includes the point of control function, Level 2 includes the control strategy and the time keeping.

TRAFFIC SIGNAL HARDWARE

Traffic signal hardware includes several elements besides the very visible traffic signal. These elements include controllers, detectors, communications interface, communications system, electrical distribution, signal indications, and other devices specific to individual systems, such as preemption control, closed circuit television (CCTV), and variable message signs (VMS). This chapter describes the different types of traffic signal hardware that can comprise a signal system.

Controllers

There are two major types of controller hardware: pretimed and actuated. Historically, pretimed controllers were electro-

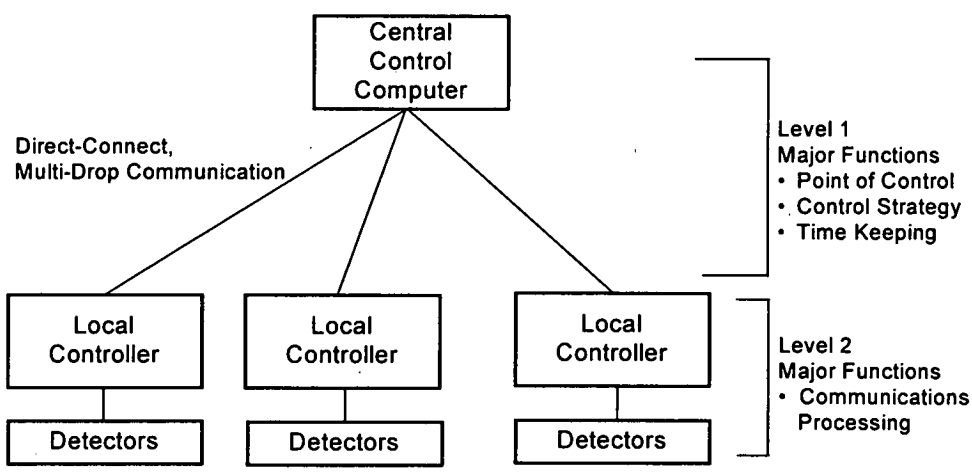

FIGURE 3 Centralized signal control system (*7*).

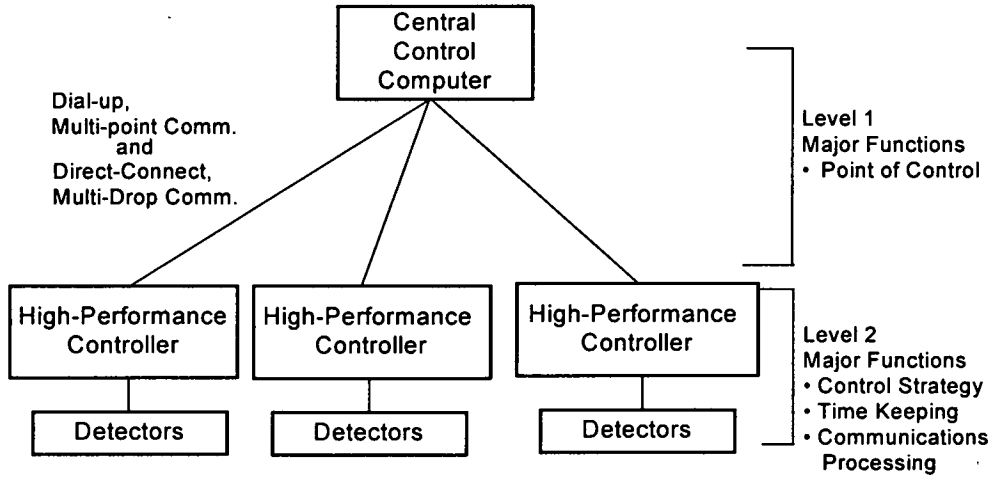

FIGURE 4 Distributed signal control system *(7)*.

mechanical devices, characterized as simple, reliable, and moderately priced. Actuated controllers, which are traffic responsive, were more complicated and more expensive. Semi-actuated and fully actuated control was achieved using local controllers and "hard-wiring" the function into the circuit (*9*).

Originally, actuated controllers were single units. If a failure occurred in the field, the entire unit had to be replaced. At that time, the objective was developing compatible units that could be switched in the field. However, this objective was not always achieved. The introduction of the transistor led to new generations of modular actuated controllers. This allowed for individual circuit boards to be replaced in the field. Also, the new modular controllers were designed so they could be expanded from semi-actuated to fully actuated control by adding detectors and circuit boards (*9*).

Traffic signal controllers, whether pretimed or actuated units, are generally housed in durable, steel-cased cabinets. Controller cabinets need to be sturdy enough to offer protection from vandalism, weathering, and impact. Cabinets typically are mounted on the signal pole, or at the intersection at street level in the sidewalk pavement adjacent to signal support poles. Presented earlier, Figure 1 shows a typical signal controller cabinet. It should be noted that the presence of cabinet casing wear and exposed wiring reveals the need for maintenance.

With the advancement of electronics into integrated circuits and then microprocessors on a single chip, actuated control moved from hardware to software implementation. This led to today's National Electrical Manufacturers Association (NEMA) and Type 179/Type 170 controllers. This modern solid-state equipment can also be used for many applications, from pretimed to the most sophisticated volume/density operation, depending on the installed software. Many cities began to replace their electromechanical equipment with solid-state equipment toward the end of the 1960s mainly because of the difficulty of obtaining replacement parts for the older equipment (*9*).

This section briefly describes the three principal types of controllers: electro-mechanical, solid-state, and microprocessor-based.

Electro-Mechanical Controllers

An electro-mechanical controller is a device that consists of moving parts to open and close electrical contacts to change the signal phases. It may be pre-timed control, based on relay circuitry, or may consist of three dials representing three signal timing plans. Generally, the timing plans are time-of-day and are AM-peak, PM-peak, and off-peak. In some cases, the "flash" function is used at night. A good maintenance program has usually resulted in the upgrading and replacement of electro-mechanical controllers.

Solid-State or NEMA Controllers

The development of solid-state traffic controllers began in the mid-1960s with a version of relay circuitry and then became more complex. Functions were combined so that where previously two or three pieces of equipment were needed, only one is used.

Modern solid-state controllers are actuated control devices designed to functional specifications developed by the National Electrical Manufacturers Association. The objective of these standards is to provide uniformity in traffic signal control equipment. NEMA standards have also been developed for detectors, conflict monitors, load switches, flashers, and general cabinet requirements.

The NEMA guidelines for traffic signal control devices can be summarized as follows (*10*):

- Industry standards for traffic-control equipment should be based on proven designs.
- Standards for interchangeable traffic-control equipment should be downward compatible.
- The industry had an obligation to take the lead in developing hardware standards.
- Every precaution should be exercised to reduce the potential for malfunctions.
- Performance and reliability of traffic-control equipment should be upgraded and should reflect the current state of the art.

NEMA guidelines, with respect to controllers, set forth specifications in the following areas:

- Logic pin assignment,
- Logic voltage ranges,
- Size of controller,
- Testing and maintenance, and
- Temperature ranges.

Microprocessor-Based Controllers

The microprocessor-based controller is another type of modern actuated controller. It can be a NEMA (discussed in the previous section), a Type 170/179, or a 2070/TS3 controller. Type 170/179 controllers are microprocessor based and are used in conjunction with the type of control implemented by software. These controllers have evolved from a design concept that emphasized the use of a single hardware device into which programs can be loaded for various applications (*9*).

The Type 170 controller was developed jointly by the state departments of transportation in New York and California. The Type 179 is a later model of the Type 170. The ITE *Traffic Engineering Handbook* describes the Model 170 as a hardware specification for standardization, providing a controller assembly package of standardized modules, complementary hardware and wiring harnesses, all housed within standard cabinets (*11*). The specifications continue to be updated to reflect technological advancements and user needs.

The 2070 and TS3 controllers represent a new generation of advanced transportation controllers (ATC). They can be retrofitted into industry cabinet standards. The TS3 is compatible with NEMA digital interfaces and the 2070 with 170 digital interfaces. The open architecture ATC "family" support off-the-shelf operating systems, are based on nonproprietary computer architecture, run open communication protocols, and can be deployed in most nonproprietary traffic control systems. These ATCs use a modular approach simplifying maintenance, providing isolation, and enabling future upgrades without replacing the entire controller. Each of the modules can be replaced, diagnosed, or upgraded individually. The modules include a VME bus computer platform, which interfaces with all other modules, a field I/O module, a 2070 modem module, a communications module, and various expansion modules (*12*). Figure 5 illustrates the module approach of the 2070 and TS ATCs.

Figure 6 illustrates the types of controllers used by survey respondents who are responsible for the maintenance of their systems. As shown, 81 percent of the respondents indicated that they use NEMA controllers in their traffic control systems. Nearly 30 percent indicated that they use Type 170 controllers. Eleven percent indicated electromechanical controllers are used in their systems, three percent indicated TMP390 controllers and three percent said non-NEMA solid-state

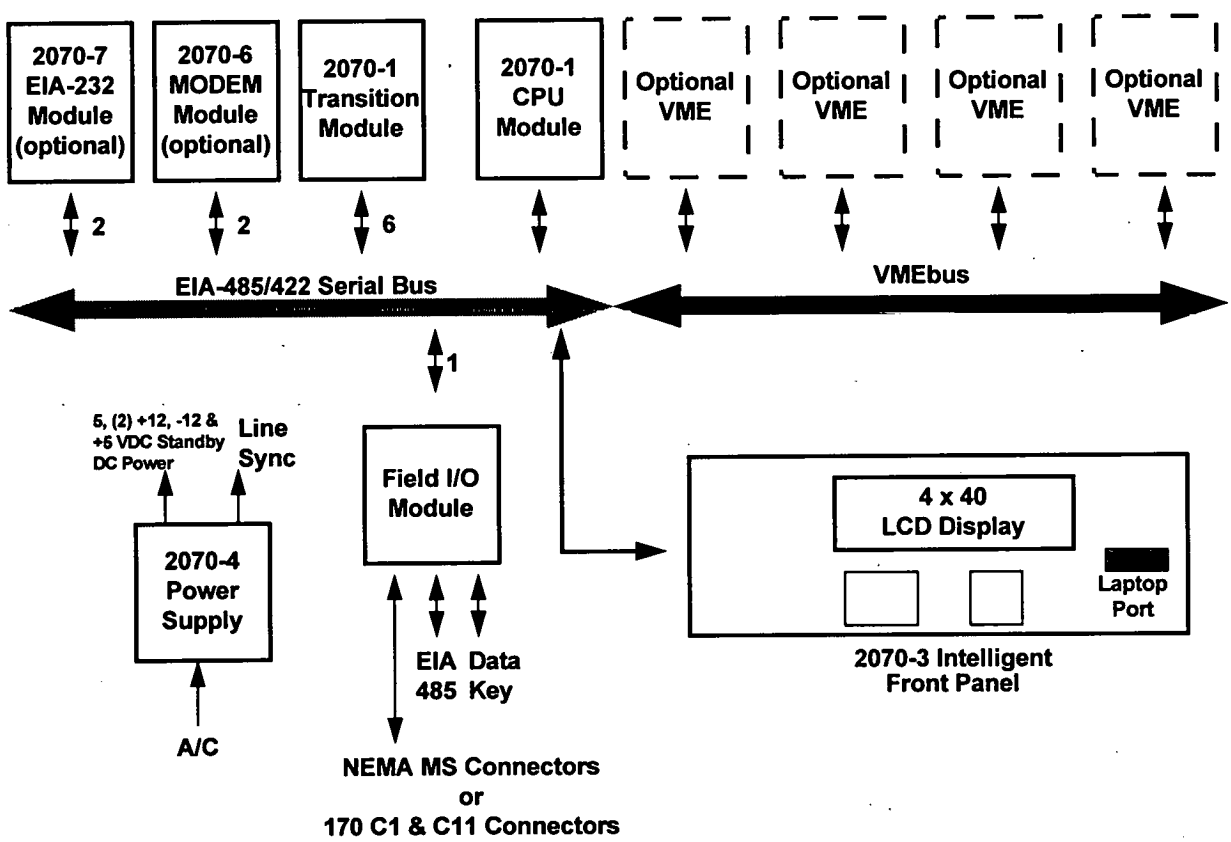

FIGURE 5 2070 advanced transportation controller (ATC) (*12*).

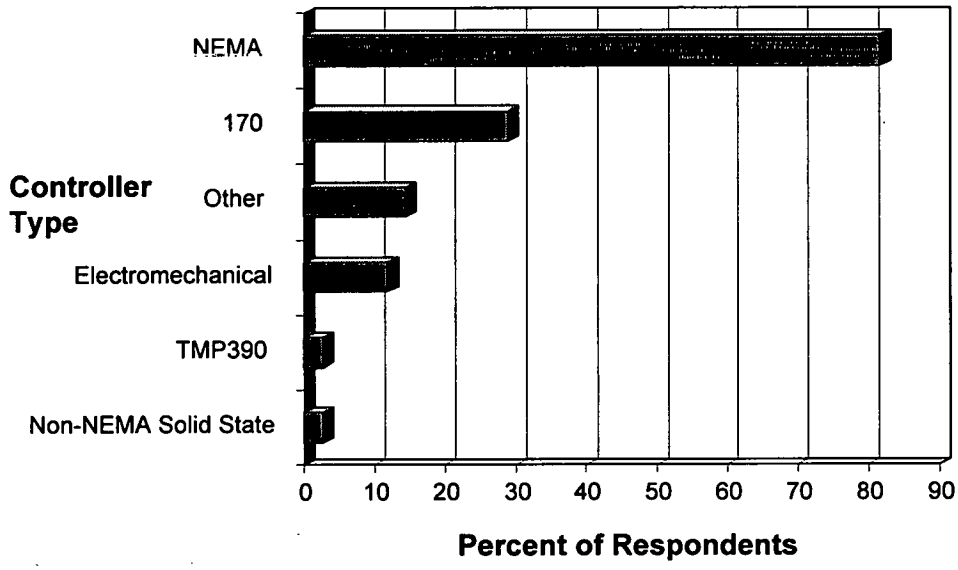

FIGURE 6 Controller types used by responding agencies.

controllers are used. Each respondent in the "other" category indicated a different type of controller, including the 180, 620/300, 820A/870, ASC2-MG1000, Eagle EF-20, HMC1000, KMC/10000, LMD-8000, Multisonic, PCE, and TR1880EL. The above percentages add up to more than 100 percent because many of the respondents use more than one type of controller.

Detectors

There are two main types of detectors or sensors—intrusive and nonintrusive. Intrusive detectors are located in the pavement surface of a roadway and detect the presence of vehicles as they pass over the sensor zone. Nonintrusive detectors are not embedded in the pavement and are usually located overhead or on the side of a roadway.

Intrusive

Inductive loop detectors are the most often used type of sensor technologies. They are embedded in the roadway and consist of a single loop or multiple loops of wire in a round, square, or rectangular configuration. Round loops are typically 6 ft in diameter and 2 to 5 in. deep. The loop is connected to a detector amplifier by a lead-in cable. The loop functions as an inductive element in the detection circuitry. The inductance decreases when a vehicle stops on a loop or passes over it and the output of the amplifier changes state to indicate the presence of a vehicle. This presence indication is then processed to provide measurements of volume and occupancy (*13*).

One of the major concerns with inductive loop detectors is reliability. Repairing and maintaining loop detectors is difficult because of the disruption to traffic. Most of the problems, however, result from poor design, improper installation, lack of inspection, or poor roadbed conditions, and not from a deficiency with the technology. Loop reliability has been improved by placing the loop deeper in the street structure, encasing the wire in plastic tubing, using better sealant, and embedding preformed loops, which consist of loop wires, in PVC conduit.

Magnetic detectors are another type of intrusive sensor technologies. The presence of a vehicle is detected by the disruption caused in an induced or natural magnetic field by the vehicle. These devices may be active or passive. Active devices, such as magnetometers, are excited by an electrical current in windings around a magnetic core. Passive devices, such as magnetic detectors, sense perturbations in the earth's magnetic field produced when a vehicle passes over the detection zone. Similar to loops, the magnetic detector's probe is connected by a lead-in cable to an electronic unit that contains the detection circuitry (*13*).

Active (magnetometer) detectors are cylinders less than 2 in. in diameter and 4.25 in. long. They are installed vertically 6 to 18 in. below the pavement surface. The detection zone is a point rather than an area such as that encompassed by a loop detector. Magnetometers detect vehicle presence and the information can then be processed to provide volume and occupancy measurements. Speed and car length can be determined if the detectors are installed in pairs. Magnetometers are useful on bridge structures, and along roadway segments with poor pavement surfaces (*13*).

Passive (magnetic) detectors cannot be used to detect presence because they require a minimum speed of 3 to 5 mph to be activated. There are two types of magnetic detectors. One is about 2 in. in diameter and 20 in. long and is installed by tunneling under the roadway and inserting the sensing probe into a nonferrous conduit. The second type of magnetic detectors is approximately 3 by 5 by 20 in. long and is encased in an aluminum housing that is mounted flush with the roadway. Because passive magnetic detectors sense changes in the earth's magnetic field over a wide area, they have a detection zone covering up to three lanes. Recent application of new digital processing technology to magnetic anomaly detection promises to significantly improve the performance of these

detectors with the possibility of tracking multiple vehicles in a multilane scenario (*13*). They also work well in pavements in poor condition.

A third type of intrusive detectors is *self-powered vehicle detectors* (SPVD). Developed with FHWA support, the SPVD consists of an in-road sensor containing a transducer, an RF transmitter with antenna, a battery, and a controller housed in a cabinet along the side of the road. The in-road sensor operates on the same principle as a magnetometer sensor. It is powered, however, by an internal lithium battery with a service life of 5 to 7 years. Data are transmitted from the in-road sensor to a roadside processor via a spread-spectrum radio link, obviating the need for lead-in or interconnecting cable. In addition to providing volume, occupancy, speed, and classification, this unit also provides data regarding pavement temperature. Up to 64 detectors can be connected to a single roadside processor, provided they are within 200 meters of the processor (*13*).

Nonintrusive Detectors

There are several types of detectors that are not embedded in the roadway surface. These nonintrusive detectors include microwave radar, infrared, passive acoustic, ultrasonic, and video imaging processing. These detectors are installed either overhead or on the side of a roadway, permitting maintenance activities to be performed with minimal disruption to the normal traffic flow. This section describes these types of nonintrusive detectors.

Microwave radar detectors direct low-power microwave energy toward a roadway. Vehicles passing through the beam reflect a portion of the energy back to the detector. Presence and speed are then measured. Some microwave radar detectors provide presence information by measuring the range from the detector to the vehicle. Other types of microwave radar use the Doppler effect to determine presence and speed of vehicles. The following are brief descriptions of four types of microwave radar detectors (*13*).

Doppler units apply the Doppler effect to detect the presence of a vehicle and are sometimes referred to simply as "radar" detectors. The beam width of a Doppler microwave radar detector can be either wide or narrow.

Wide-beam units are usually installed in locations where only the general speed of the traffic flow is needed. A vehicle's speed is measured when it enters the beam. If more than one vehicle enters the beam during the same second, the speed of the largest vehicle is usually recorded. Only one detector is required and it can be mounted over the center of the roadway or at the side.

Narrow-beam units are installed where lane-specific volumes and individual vehicle speeds are needed. An individual detector is mounted over each roadway lane.

Long-range detector units are a version of the wide-beam detectors. However, unlike the wide beam detector, they can be set back at a greater distance from the roadway.

Ultrasonic detectors use sound waves within a range of frequencies between 20 and 65 kHz to receive range or Doppler speed data. The sound waves are transmitted by the detector from forward-looking or side-viewing transducers into an area defined by the beam width pattern. The road surface or vehicle in the area reflect a portion of the energy back so presence and speed can be determined. This is accomplished by the transducers that convert the sonic energy received into electrical energy, which is fed to signal processing units either co-located with the transducer or located in a roadside controller. There are two main types of ultrasonic detectors (*13*):

- Range-measuring detectors transmit a series of pulses with a width between 0.02 and 2.5 msec and a repetition between 33 and 100 msec and then measure the time it takes for the pulse to reach the vehicle and return. A user-adjustable interval is included in the receiver to help differentiate between pulses reflected from the roadway surface and pulses reflected from vehicles.
- Speed-measuring detectors transmit a continuous wave of ultrasonic energy. The passage of a vehicle is detected by a shift in the frequency of the signal received. Speed of the vehicle can then be determined from the pulse width of an internal signal, generated by the detector's electronics, that is proportional to the speed of the detected vehicle.

Infrared detectors can be either active or passive detectors. Active detection zones are illuminated with low-power infrared energy supplied by light-emitting diodes (LEDs) or laser diodes. The infrared energy reflected from vehicles traveling through the zone is focused by an optical system onto a detector matrix mounted on the focal plane of the optics. Real-time signal processing techniques are used to analyze the received signals and to determine the presence of a vehicle. Changes in received signal levels caused by environmental effects such as weather, shadows, and thermal heating can be automatically corrected by the processor (*13*).

Passive infrared detectors provide presence information using an energy-sensitive detector element to measure the change in energy emitted when a vehicle enters its field of view. No energy is transmitted by the detectors. Blackbody radiation is the source of energy, which is produced by the nonzero temperature emissive objects.

Passive acoustic detectors use an array of microphones to detect and verify the unique acoustical sounds of vehicular noises such as engine noises and tires on pavement. The detector processes these sounds to provide spatial directivity. Detection zone size and shape are determined by the sensor aperture size, the processing frequency band and the installation geometry. When a vehicle passes through the detection zone, an increase in sound energy is detected by the signal processing that is part of the acoustic array and a vehicle presence signal is generated. When the vehicle leaves the detection zone, the sound energy level drops below the detection threshold and the vehicle presence signal is terminated. Because of sound reverberation from the walls and ceiling, passive acoustic detection is not suitable for tunnels (*13*).

Video image detectors employ video technology and image processing techniques. Video cameras installed at selected locations along the freeway or at signalized intersections collect a variety of real-time traffic data. Traffic can be detected at a number of locations within the camera's field of vision.

Therefore, this type of system has an advantage over loop detection in that video cameras have the capability of wide-area detection and can replace several loops. Video image detectors can collect most of the presence and passage detection indicators that are outputs of typical loop detectors such as volume, lane occupancy, speed, etc. Two concerns with the accuracy of video detection systems have surfaced: vehicle occlusion and transition from day to night or changes in lighting shades. A number of counties and municipalities currently use image processing detection technology (*14*).

Communications

Communications devices provide for the transmission of information between signal system components. The type of communications medium is determined by the type of control and the data being transmitted. There are two main types of data transmission media for traffic signal control systems: wireline and wireless.

Wireline

The four main types of wireline communications media usually used for control systems include (*11*):

- Conventional interconnect cable,
- Twisted-pair cable,
- Coaxial cable, and
- Fiber optic cable.

Wireless

Wireless communications transmit data through the air without the use of cable technologies, as implied by the name. Otherwise known as "air-path" media, wireless communications devices can include the following technologies: spread spectrum radio (SSR), microwave, satellite, and cellular radio.

Wireless technologies are used most often in special situations such as at water crossings and in remote locations to connect them with the central system. The 900 MHz band used by many SSR providers have become very crowded in large cities. It is expected that higher bands will see increased activity with the same result.

Electrical Distribution

Electricity can be distributed in two basic ways: overhead and underground. The function is to distribute electrical power to the controller and between the controller and devices. Underground wiring is usually installed in conduits. Voltages to devices such as signal heads usually are 110 VAC, 170 controller equipment is 12 VDC and 24 VDC for NEMA controllers and pedestrian actuation buttons. Voltage drop caused by long runs of wire between the service point and the signal controller can cause major problems with the reliability of processor-based devices.

Signal Indications

Today, there are more than 300,000 traffic signals in North America (*15*). They can consist of red, yellow, and green indications and can include directional arrow indications in all three colors for protected left and right turns. Pedestrian signals and illuminated signs are other examples of signal indications.

The equipment and materials used for traffic signal indications have evolved as well. Presently, most signal indications are incandescent lamps with a colored lens to display red, yellow, green, and arrows. The city of Los Angeles has experienced a problem with the quality control of delivered bulbs. Shop and field testing, including accelerated life testing, and a change in specifications has been helpful. Recently, signal indications have been developed that use light-emitting diodes (LEDs) in place of incandescent bulbs.

LEDs are solid-state devices that use luminescence to produce light. Presently, LEDs are most often used for red light indications because the greatest concern for burn-out is the "Stop" or red indication. Energy savings of LEDs over incandescents has been found to be approximately 85 percent. As a basis for comparison, a 12-in. incandescent lamp uses a 150-watt lamp, while the average 12-in. LED uses 25 watts. The life-expectancy of an LED is 100,000 hours, at which point its intensity will degrade to half; however, failure is rare. A power factor correction is necessary to achieve maximum energy savings.

LEDs can differ from one manufacturer to another with respect to die material, epoxy material, positioning of the die cup, and size and shape. Brightness is not dependent on the size, but on the semiconductor die inside, which emits the light.

With regard to die materials, the AlInGap LED is the newest in die material design, whereas the AlGaAs has been the LED of choice for high-intensity applications. However, several flaws are associated with the AlGaAs, including premature dimming and degradation when exposed to excess heat and humidity for long periods of time. The AlInGap does not contain aluminum in the top of its die structure and therefore does not have this problem.

Another development in signal indications is a bi-modal arrow signal head that uses LEDs and retrofits into standard housing. The signal head has the ability to go from green to yellow, two indications in one space. The LEDs are alternated within the signal display and are lit according to the programmed phase. Some concern has been expressed by color-blind motorists.

Control Methods

There are two main types of traffic signal control: local and central. Local control is achieved using one or more controllers to operate the traffic signals at an isolated intersection or a series of adjacent signals. Central control is accomplished by operating a controller or controllers from a centrally located source. Each of these control methods can operate signals as fixed-time, semi-actuated, or fully actuated.

Fixed-time, the most basic type of control, is provided by programming a controller to implement timing plans at specific times of the day (*16*). Sometimes known as time-of-day, cycle lengths and phases of fixed duration are preset and regularly repeated based on the predetermined time-of-day patterns of traffic (*11*). For example, a separate timing plan can be programmed for morning peak, afternoon peak, and off-peak traffic.

The purpose of semi-actuated control is to allow the "main" street, which has the larger traffic volumes, to have a longer green time than the "cross" street and to be interrupted only by the presence of vehicles on the cross street. Detectors are typically installed on the cross street to "call" a change in phase only if a demand exists. To serve the cross street demand, there are three types of phase intervals: minimum (basic) green time, passage interval (time it takes all detected vehicles to pass loops, and maximum green time ("force-off"). Pedestrian push buttons can also stop the main street traffic for pedestrians to cross. In progressive signal systems, the semi-actuated control can be set to permit main street interruption only at specific times during the cycle length (*9*).

Fully actuated control is achieved by installing detectors on all approaches to an intersection. Variations in signal timing and phases occur with fluctuations in traffic demands as identified by the detectors. This type of control is usually implemented at intersections where the demand level varies significantly in all directions, providing a more responsive signal to traffic demands (*9*).

Other Devices

Several other devices can be incorporated into a traffic signal control system. These devices enhance control and operation and improve safety. This section describes several types of these devices.

Preemption Control

Preemption or priority systems include traffic control strategies that assign priority for the movement of specific types of vehicles such as buses, emergency vehicles (fire and police department vehicles), and railroad cars on at-grade crossings. Preemption control devices or control strategies have been developed to satisfy the required signal display modifications. Signal installations near fire stations and railroad grade crossings sometimes require modifications to the existing signal sequence. For example, a fire department's emergency preemption control allows all signals to turn red, stopping traffic so the fire trucks can proceed quickly through an intersection. Similarly, preemptive signal control is configured to provide right-of-way to transit vehicles. The older traffic control systems may require additional external equipment for preemption. The modern microprocessor equipment may require software additions or modifications for this type of control. In all cases, the operation of preemption devices (railroad, fire, etc.) should be checked on a timely basis to carry on effective maintenance practices. Maintenance deficiencies can result in a variety of equipment malfunctions or breakdowns, or reduced service life similar to ordinary traffic signal control devices. Typical preemption control device malfunction or breakdown could be detector failures, loss of interconnected (to the signal) control, or a loss of signal indication at the junction due to equipment outage. Proper and scheduled maintenance procedures can significantly reduce the risk of equipment malfunction and increase the overall service life of the control devices (*14*).

Closed Circuit Television

Closed circuit television (CCTV) has been found to be the most effective way to monitor the operation of a traffic management system. It uses visual surveillance equipment to locate traffic congestion and incidents from a remote location. The major components that comprise a CCTV system are field equipment, communication media, and central equipment. The following are the main functions of CCTV devices (*13*):

- Detection of incidents
  - –Verification of incidents
  - –Verification that incidents have been removed
  - –Verification of messages and displays (if applicable)
  - –Provision of visual information on adjacent roadways such as major cross streets
- Counting
  - –Control of ramp meters.

Some agencies have experienced difficulties with mounting heights of CCTV. In some cases, their maintenance equipment was not sufficient in that the CCTV was mounted on a 60-ft pole and the agency's bucket truck could not go higher than 45 ft. In other cases there was no maintenance turnout for the bucket truck and one or two freeway lanes needed to be closed to perform maintenance, an example of maintenance causing unnecessary congestion.

Variable Message Signs

Variable message signs (VMS), frequently referred to as changeable message signs (CMS) provide real-time information to motorists pertaining to traffic conditions. An example of a well-maintained VMS used to provide motorists with real-time parking conditions in St. Paul, Minnesota is illustrated in Figure 7. The signs are dynamic and can be changed from a central, remote location such as a traffic operations center. There are several types of VMS ranging in size and technology. The most common form of VMS is the matrix sign which can be of character, line, or full-matrix configuration. Sign technology includes the bulb matrix, flip disk, LED, fiber optic, and hybrid.

A character matrix provides an individual module for each letter or character. The spacing between letters and maximum

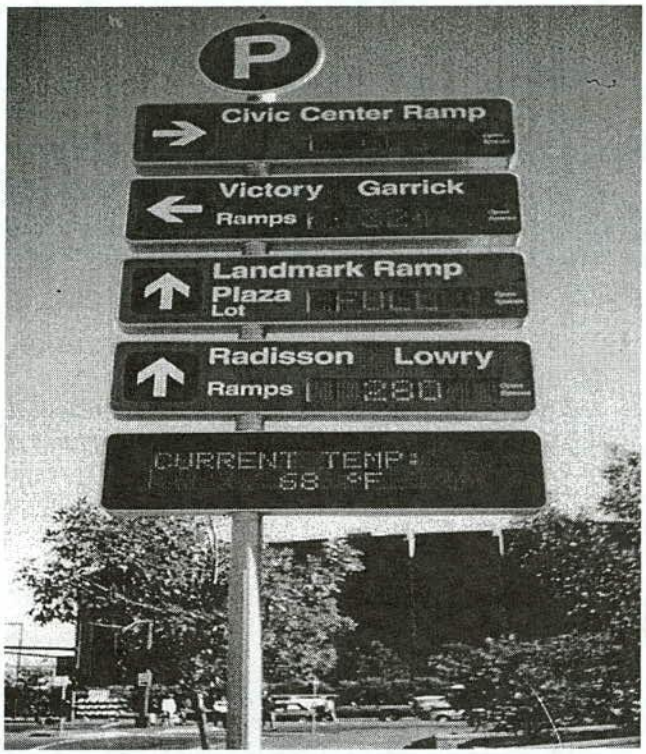

FIGURE 7 A well-maintained advanced parking management system sign, St. Paul, Minnesota.

letter width are fixed. In a line matrix, a module is provided for each line. This limits graphical abilities, but allows for proportional letter spacing. The full matrix has no built-in divisions between letters or lines. This type of VMS allows the greatest flexibility in size and stroke of the letters and allows for graphical displays. For example, the full matrix can display three lines of 18-in. letters or two lines of 24-in. letters (*13*).

With respect to sign technology, the bulb matrix uses incandescent lamps, which when turned on and off, produce a desired message or design. They provide excellent visibility during the nighttime and daytime hours. Maintenance requirements for bulb matrix, however, are high because individual bulbs must be replaced when they fail (*13*).

The flip disk VMS consists of a matrix of disks that are reflectorized on one side and black on the other. The disks are magnetically "flipped" in the desired pattern to form messages. This technology, however, does not generate its own light and is dependent on natural lighting conditions. Artificial light is applied during periods of darkness, but visibility is not optimal (*13*).

Light-emitting diodes (LEDs) are another type of VMS technology. LED clusters are mounted in a socket to form a pixel of the display. They provide good visibility under most conditions and are available in a variety of colors including red, green, amber, and red-green hybrid (*13*).

Fiber optic VMS consist of bundles of fiber optic cables that terminate in dots on the face of the display. Two dots combine to form one pixel. The light source is usually one 50-watt tungsten bulb per three characters. Visibility of fiber optic VMS is very good under all conditions, however, there are several maintenance problems associated with them. The mechanical shutters can be difficult to maintain, the lamps need to be replaced periodically, and the technology is currently available only from European manufacturers, making it difficult to get replacement parts (*13*).

Hybrid VMS, a mix of flip disk and LED or fiber optic technologies, consists of flip disks with a small hole in the center. A fiber optic bundle or LED is placed behind each hole. When the reflective side of the disk is visible ("on") the light supplements the reflective surface. When the nonreflective, or black surface is visible ("off") the LEDs are turned off or the fiber optic bundle is concealed (*13*).

Highway Advisory Radio

Highway advisory radio (HAR) is a local area, broadcast based technology that provides traffic information to motorists in their vehicles. Low-powered transmitters with a range limited to several miles are located along the roadway and the broadcasts are received through AM radio frequencies on an individual vehicle radio.

Handheld Devices

One type of handheld device recently introduced in traffic control systems is the bar code reader. Bar codes are installed on equipment and parts for inventory and diagnostic purposes and a reader is needed to read the codes. Another type of handheld device is the laptop computer. Laptops can be used in the field for signal inventories and to access and transmit files to and from the field and a central location.

Global Positioning Systems

GPS use signals transmitted from a network of satellites that are already in orbit and receivers that are hand-held or placed on the roof of vehicles. The equipment reads the transmission from satellites that triangulate the latitude and longitude position on the earth's surface and provides a readout of that position or sends the location to dispatch. In areas where a satellite signal cannot reach, such as underground or in urban canyons, the system maybe combined with another type of automatic vehicle location (AVL) system. Because the military employs selective availability of satellites, the position accuracy may be decreased or require a longer time to establish a location. Differential GPS (DGPS) helps to reduce this inaccuracy by placing a receiver at a known stationary site. The difference between the known location and the GPS measured location is then used for calibration (*17*).

Supports

Supports are needed on which to locate traffic control devices (signs, signals) for optimum viewing by motorists and to

locate other devices (controller) for ease of maintenance. The materials for these supports can be steel, aluminum, concrete, or wood. Traffic control devices are mounted on poles, span wires supported by poles, and mast arms supported by poles. Other devices are typically pole mounted.

Lightning Protection

The embedded loop detector wire and the aerial interconnect cables can act as antennae and they are susceptible to lightning strikes. Because these wires are connected to equipment, mostly solid-state inputs, they require some kind of protection. The protection usually is the application of a lightning arrester that minimizes the possible damage to the solid-state circuit component when lightning strikes. In all cases the system must be adequately grounded.

Uninterruptable Power Supply

A UPS is usually added to the system to continue system operation for a predetermined time, minimize the loss of data, and provide notification of power loss. The addition of this standby device is necessary where the data are irreplaceable, processing and storage are sensitive to loss of power, and recording of power failure is important. A UPS may also be used at critical field locations in anticipation of future low voltage.

PROCUREMENT

Many different methods can be used to procure a system. Procurement processes include low-bid, prequalifications, design-build, life-cycle costs, privatization, and facilities management. A description of these, as obtained from the survey, is contained in Appendix D.

CHAPTER THREE

TRAFFIC SIGNAL CONTROL SOFTWARE

The first computer used to control traffic signal systems was an expensive mainframe with limited capabilities. Computers have now evolved into more advanced, affordable, and reliable machines capable of using a variety of operating systems to run sophisticated software applications. This chapter provides a brief description of the available traffic signal control software and operating systems that will require maintenance.

DEVICES

Solid-State/NEMA

NEMA TS2 controllers have been developed to operate in a controlled, or real-time local mode. Internal software (or firmware) provided by the manufacturer functions as a signal switching unit. NEMA TS2 controllers compute timings and process status data provided as detector inputs. The ASC/2 series NEMA TS2 controller can operate in any one of eight I/O modes. These modes assign specific functions to 24 input and 24 output connections. This controller can also be programmed to operate as a TS1 unit (*18*).

Model 170/179/170E/170S

The model 170 controller assembly (hardware, module, and control cabinet) uses a microcomputer that, with the addition of appropriate control software, can operate in a variety of control applications. The development of a control program that provides the requirements for the local control functions requires a detailed knowledge of the 170 software. A number of traffic control programs are available to provide control, some that can be specially designed to meet the specifications of any jurisdiction. The available programs of the 170 software include:

- Multi-phase operation,
- Semi- and fully actuated operation,
- Diamond interchange control,
- Ramp metering, and
- Other ITS related operations and control.

The Type 170E controller is a version of the 170 with four communication ports and two internal communication modem cards. This Type 170E can operate nearly all traffic applications from two-phase intersections to computerized network systems. With the implementation of various software packages, the 170E can be used in ramp metering, count stations, VMS control, sprinkler control, and pump control (*19*).

Advanced Traffic Controller (ATC-2070 type)

Advanced traffic controllers (ATCs) are powerful and flexible processing platforms that incorporate open computer standards. This openness allows system integrators to configure a system without the constraints of limited computer architecture. ATCs also provide compatibility and interchangeability of hardware components from various vendors. An ATC has the following capabilities:

- *Compatibility of applications*: Software applications can be developed in high-level, user friendly environments resulting in compatible application programs.
- *High processing power*: ATCs have the capability to run high-level applications allowing for the implementation of distributed computer architecture and modern control algorithms, such as adaptive traffic control systems.
- *Fast data transmission rate*: ATCs are capable of transmitting serial data at megahertz rates as opposed to the kilohertz rates for model 170S controllers. This capability allows data to be transmitted more frequently to operations centers and other processing platforms.
- *ITS compatibility*: The ATC is capable of simultaneously controlling video surveillance cameras, VMS, and other ITS technologies as well as local signals. All these tasks can run simultaneously within a single 2070 controller.

The ATC 2070 type supports OS-9 and other real-time operating systems. Third party software, which is not an integral part of the 2070, is available from vendors or manufacturers, and can be installed for intersection control, communications, and other applications (*20*).

National Transportation Communications/ITS Protocol

The main objective of the NTCIP, a set of communication standards, is to establish interoperability and interchangeability between devices of the same type and allow a wide selection of equipment to be procured. For example, in a situation where equipment must be replaced, a technician will not have to worry about having the "right brand" on the truck. The goal is to achieve this level of compatibility by applying existing communications standards and models (*21*). An industrywide team has been assembled to establish these standards.

NTCIP will support the integration of ITS technologies and allow traffic engineers to attach different field devices such as controllers, VMS, and ramp meters to one communications line. It will also allow agencies to procure signal equipment

from multiple vendors over a system's life, resulting in a significant cost savings (*22*).

APPLICATIONS SOFTWARE

The Urban Traffic Control System (UTCS) was initiated by the FHWA as a research and demonstration project. The objective was to test computer-based control strategies to improve traffic conditions. This plan included three generations of control. The first generation of UTCS utilized a library of prestored timing plans. Each plan was developed off-line using optimization programs. The second generation of UTCS used timing plans computed in real time, which were either based on forecasts of traffic conditions or on roadway detector information. The third generation of control was envisioned to be an improved version of the second generation in that it would have a short control period, and include a queue management feature (*11*).

The second and third generations of UTCS were never developed for widespread use, however, first generation UTCS is common and a 1-1/2 generation has also been developed. These two systems are described in the following paragraphs.

The first generation of control is based on timing plans developed from historical data. They are stored and selected by the system operator on a time-of-day basis or according to recently measured traffic conditions. Timing plans are usually updated at 15-minute intervals and smooth transition between the plans is achieved through a transition routine that is part of the system (*11*).

UTCS 1-1/2 generation control is used to identify when predesigned timing plans are no longer satisfactory and to compute new timing plans for review by traffic engineers. This type of control was developed to overcome the difficulty of fine-tuning timing plans. Extensive data collection and labor-intensive analysis is required to maintain the effectiveness of signal timing plans (*11*). There are many different types of traffic signal systems control software, as described in the literature (*23*).

Optimization and Simulation Software

Several types of applications software are available to simulate and optimize traffic conditions. These programs are generally used for off-line timing plan computation. Each was developed for specific operating systems. This section describes some of the available public domain applications software.

PASSER-II, III, and IV

The Progression Analysis and Signal System Evaluation Routine family of programs can optimize the operation of an isolated intersection or a network of intersections, including progression along an arterial (*11*).

TRANSYT-7F

The Traffic Network Study Tool is similar to PASSER-II in data base requirements. It is a network simulation package originally developed in 1968. The "7" denotes the version number and "F" indicates that it is the FHWA version of the TRANSYT-7 model developed by the Transport and Road Research Laboratory in England. The basic characteristics of TRANSYT-7F are (*11*):

- Macroscopic, deterministic traffic flow model that can be used to compute a performance index based on measures such as delays and stops for a given signal network and timing plans.
- Hill-climbing procedure that can be used to make changes to signal timings.

Arterial Analysis Package

AAP was developed to ease the data input process of PASSER-II and TRANSYT-7F. The program allows data input by the user. The user can then generate an input file for either program depending on their needs and preferences (*11*).

Traffic Signal Optimization Model, Version III

SIGOP III is similar to TRANSYT-7F in that it is a macroscopic analysis tool and it contains a traffic flow submodel and an optimization submodel. It differs in that it also considers queue spillover in addition to stops and delays in its performance index (*11*).

Traffic Network Simulation Model

TRAF-NETSIM is a microscopic simulation model to evaluate proposed operational improvements to signalized networks, such as adding or deleting lanes, converting bidirectional to one directional flow, and installing new signals.

Freeway Simulation Model

FRESIM provides for microscopic simulation of freeways to evaluate geometric changes and operational features, such as lane-changing, ramp metering, surveillance systems, different vehicle types, and vehicular lane restrictions.

Corridor Flow Model

CORFLO is a macroscopic simulation model for integrated urban network or corridor analysis that has traffic assignment capabilities. Automobile, truck, bus, and carpool flows on

freeways and surface streets can be analyzed in a single integrated environment.

Signal Grid Program

Another optimization program for signal networks is SIGRID, an application developed for the Toronto traffic signal control system. The program can calculate the optimal offset differences for a network using a given cycle length, signal splits, link data, and a set of desirable offset differences input by the user (*11*).

There may be other applications available that are not discussed in this chapter, however, those mentioned are the most often used programs. Subsequent versions, when they are developed, become available as upgrades from vendors or manufacturers.

Operating System Software

Most of the applications programs are written in FORTRAN IV for use on 16/32-bit computers and most microcomputers. MS-DOS based microcomputer versions are available for most applications with user interface programs written in Pascal. In addition, most of these programs operate in an OS/2 or UNIX environment on IBM-compatible computers and require at least a 386 processor and 8M RAM. Some applications can be operated on a desktop computer with a 286 processor and 4M RAM, PASSER-II is an example. Some systems operate in OS/2 or UNIX environments on 486- or Pentium-based desktop computers and can be operated on one computer or a network of computers. They can be operated in DOS or Windows environments and many are being developed for use with Windows NT. Upgrades to these systems, such as memory and processor upgrades, are available through vendors and manufacturers.

Maintenance Management Systems

Computerized maintenance management systems are available and are being used by some larger jurisdictions to improve the efficiency of their operations and to cope with increased equipment use. These systems can be part of an applications package or function as stand-alone systems. System components usually include a central processing unit, field units (usually hand-held or laptop), a bar code reader, and a communications capability. Communication can be implemented through a packet data interface with almost any of the voice radio dispatch systems now in use, or through an "order wire" channel within the signal interconnect system. In some cases a global positioning system (GPS) unit is used to automate location input to the system. Attributes of such a system are included in Table 1.

Software products that manage traffic engineering assets are currently in use. One technical paper describes a software that effectively integrates geographical information systems (GIS) with relational database management systems (RDBMS). Among the many functions available, the software enables city, county, and state traffic engineers to create and maintain inventories of the geographic locations and detailed attributes of assets such as traffic signals. The software also allows engineers to print maintenance orders for field crews showing the map locations and attributes of traffic signals to be replaced or repaired, automatically updates the field inventory when maintenance orders have been completed, and maintains a detailed file of all maintenance activities associated with each signal. In this software, the GIS supplies the mapping capability and the RDBMS provides the attributes for the GIS-mapped locations and together they enable the agency traffic engineers to more effectively manage the components of their traffic signal system (*25*). The Minnesota Department of Transportation (Mn/DOT) has used a maintenance management system for the last 3 years. It was developed by an outside contractor and is being operated and maintained by department personnel. The system is used to manage the maintenance of traffic signals, lighting, counting devices, and traffic management devices. Figure 8 shows a system printout of a statewide signal list. The system is PC-based and operates on a local area network using the Oracle program. All district offices input their own data over a wide area network. In the future, field forces will be able to input data from laptop computers with a cellular phone capability and will use bar codes to track inventory for traffic signals and traffic management devices.

Commercial maintenance management systems are available as a module of system software or as a stand alone application. The module features management and reporting of daily functions that involve traffic signal system equipment. One such process uses a bar code reader and includes trouble calls, equipment repair logs, statistical failure rates, status of work, and individual component information. Figure 9 illustrates a data entry form to record inventory status from a commercially available system.

Diagnostics

Diagnostics is a procedure to detect if an equipment problem exists and determine what the problem is so that a solution can be developed and applied. Devices are available to diagnose equipment malfunctions; this section describes some of them.

Software

Software diagnostics programs facilitate computerized maintenance through detection and isolation of malfunctions, errors, and operational problems. Data bases are used to organize this information and incorporate date, time, and location of any malfunctions, and maintenance activity performed. From these data bases, reports can be generated providing detailed information about equipment problems. Maintenance personnel can download data into the databases from the field using laptop computers. They can also receive intersection and equipment information on-site through modem communications or via

TABLE 1

ATTRIBUTES OF A TRAFFIC CONTROL DEVICE MAINTENANCE MANAGEMENT SYSTEM

Overall System
Efficiency and use of manpower
Reduce paperwork
Improve communications with staff and public
Upgrade traffic control devices
Improve safety by being more responsive
Improve risk management
Maintenance Management System
Modular network computer system
GIS/Windows graphics display
"Off-The-Shelf" equipment and software
Integration with inventory, accounting, GIS, accidents, traffic volumes and other records systems
Integrate with software for highway capacity, signal timing, signal analysis, and sign design details
Future adaptation to metric, retroreflectivity, and CADD's plan sheets
Graphic display systemwide, roadway segment, and intersection illustrating roadway, devices and device details
Inquiry by GIS, street name, street address or map display
Field Inventory and Records Maintenance
User friendly data entry
GPS reader directly into system
Windows Screen display to select options on field work
Screen display of existing inventory records
Bar code entry of materials
Automatic accounting for man-hours, equipment, and material
Future use of cellular phone, modem or other communications systems
Electronic audit of data entries for errors
Use of same equipment for inventory and maintenance entries
Inventory and maintenance data entry done concurrently
Personnel training programs on systems, inventory, data entry
Field Crew Applications
Schedule maintenance work
Take right material to work site
Locate all devices with specific attributes
Provide specific details on all devices
Automatic stock re-order on materials
Graphic display of devices, installation, and roadway
Graphic display of sign details
Systemwide, road segment, or intersection display for review or monitoring of devices
Resolve maintenance questions without field review
Maintenance Management Applications
Develop budget, personnel, and accounting reports
Respond to inquiries and complaints
Make device decisions without field reviews
Produce summaries and illustrations for correspondence, reports, and presentations
Historical records for litigation
Provide management analysis systemwide, maintenance activities, TCD details, and costs
Provide current warehouse inventory
Generate maintenance work orders with drawings
Produce standardized periodic reports based on agency practices
Custom sort data for any combination of variables
Plan and program device improvements
Provide maintenance program scheduling and monitoring

Developed by J.A. Pline, Boise, Idaho (1996).

cellular radio transmitted by the system operators. Commercial off-the-shelf software can be purchased and installed for maintenance activities and inventory or a software specifically developed for traffic can be installed to perform maintenance management, diagnostics, and inventory control of the existing system (*26*).

Equipment

A malfunction management unit (MMU) is used to diagnose problems and failures with intersection devices such as controllers. An MMU can detect and display problems related to the yellow plus red clearance interval, dual indication on the same channel, difference between actual load switch output and programmed controller output, fault in selecting the proper function, blinking, noise, or dimming, voltage drops, and absent or improperly seated card.

Loop detector monitors can also be installed to monitor faults with system loop detectors. These monitors indicate watchdog failure, open circuit failure, short circuit failure, and excessive change in inductance value. LEDs are used to indicate failures. When the red LED is lit, detection is indicated.

STATEWIDE Signal List as of September 1995 Page 73

TH	Location	ID	Type	Pr	D	Ar	City	County	Power Company
61	55 MASTER (61=VERMILLION)	21001	MCB		D	ME	M3 Hastings	DAKOTA	Northern States Power Company, Minnesota
	Cabinet SM	EVP NA	Hardware NA		Luminaire NA	Relamping	Non EVP		
61	10TH ST (61=VERMILLION)	21002	TEL		C	ME	M3 Hastings	DAKOTA	Northern States Power Company, Minnesota
	Cabinet SM	EVP NA	Hardware SM		Luminaire MM	Relamping	Non EVP		
61	S OF 8TH ST SB	21003	WFL		D	ME	M3 Hastings	DAKOTA	Northern States Power Company, Minnesota
	Cabinet SM	EVP NA	Hardware SM		Luminaire NA	Relamping	Non EVP		
61	4TH ST (61=VERMILLION)	21004	ISO		C	ME	M3 Hastings	DAKOTA	Northern States Power Company, Minnesota
	Cabinet SM	EVP NA	Hardware SM		Luminaire MM	Relamping	Non EVP		
61	HADLEY AV-GRANGE BLVD	21005	TEL		C	ME	M3 Cottage Grove	WASHINGTON	Northern States Power Company, Minnesota
	Cabinet RM	EVP RM	Hardware CM		Luminaire MM	Relamping	Non EVP A99480		
61	GRANGE/80TH E RAMP	21006	TEL		C	ME	M3 Cottage Grove	WASHINGTON	Northern States Power Company, Minnesota
	Cabinet SM	EVP SM	Hardware SM		Luminaire MM	Relamping	Non EVP		
61	80TH-HARKNESS	21007	UNK		N	ME	Cottage Grove	WASHINGTON	Northern States Power Company, Minnesota
	Cabinet MM	EVP NA	Hardware MM		Luminaire NA	Relamping	Non EVP		
61	HADLEY/GRANGE (MASTER)	21008	MCB		D	ME	M3 Cottage Grove	WASHINGTON	Northern States Power Company, Minnesota
	Cabinet RM	EVP NA	Hardware CM		Luminaire NA	Relamping	Non EVP A99882		
61	GRANGE/80TH W RAMP	21009	TEL		C	ME	M3 Cottage Grove	WASHINGTON	Northern States Power Company, Minnesota
	Cabinet SM	EVP SM	Hardware SM		Luminaire MM	Relamping	Non EVP		
61	610' S OF 12TH ST	21010	AFL		A	ME	M3 Newport	WASHINGTON	Northern States Power Company, Minnesota
	Cabinet SM	EVP NA	Hardware SM		Luminaire NA	Relamping	Non EVP		
61	12TH ST (61=10)	21011	TEL		B	ME	M3 Newport	WASHINGTON	Northern States Power Company, Minnesota
	Cabinet SM	EVP SM	Hardware SM		Luminaire MM	Relamping	Non EVP		
61	590' N OF 12TH ST	21012	AFL		A	ME	M3 Newport	WASHINGTON	Northern States Power Company, Minnesota
	Cabinet SM	EVP NA	Hardware SM		Luminaire NA	Relamping	Non EVP		
61	580' S OF GLEN RD	21013	AFL		A	ME	M3 Newport	WASHINGTON	Northern States Power Company, Minnesota
	Cabinet SM	EVP NA	Hardware SM		Luminaire NA	Relamping	Non EVP		
61	GLEN RD (61=10)	21014	TEL		A	ME	M3 Newport	WASHINGTON	Northern States Power Company, Minnesota
	Cabinet SM	EVP SM	Hardware SM		Luminaire MM	Relamping	Non EVP		

FIGURE 8 Mn/DOT computerized maintenance management system.

A lit amber LED indicates failure and flashing red and amber together indicates an on-going fault condition (*27*).

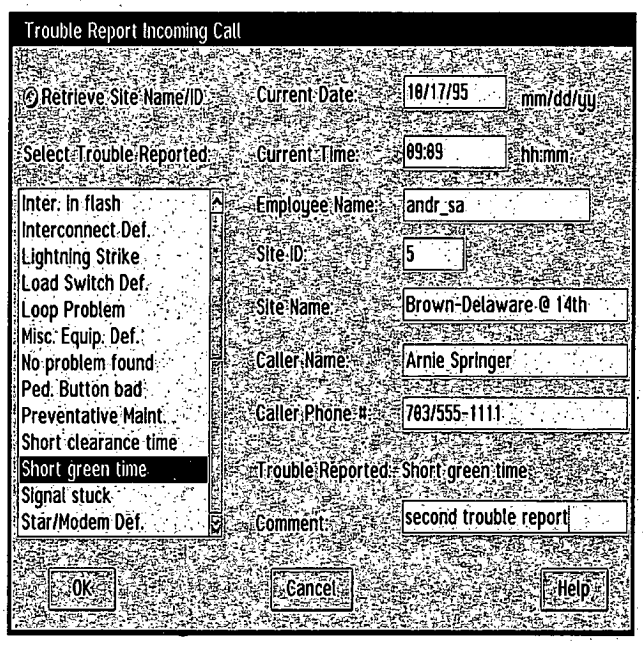

FIGURE 9 MIST® inventory data entry form.

The Maryland State Highway Authority (MDSHA) has a communications link with 500 signalized intersections. Through this link, repair history records are provided that include equipment failures and failure messages. The records can be reviewed to determine when and where detector failures have occurred. The system generates the following messages associated with detector failures (*28*):

- *Maximum presence:* A vehicle is registered in the detection zone for a period longer than the maximum allowable time.
- *Minimum presence:* A vehicle is registered in the detection zone for a period shorter than the minimum allowable time.
- *No activity*: No vehicles are detected for an extended period of time.

Automatic conflict monitor testers can be used to identify run fault checks on traffic signal conflict monitors. Many of these devices are compatible with both NEMA and 170-type conflict monitors. The tester can be programmed to automatically run a series of tests on the conflict monitor and prints a performance report detailing the test results (*29*).

Expert Systems

In a traffic management system, device failures can be continuously checked and displayed on a zone monitor or at

the zone master. A failed device can be identified by selecting a fault isolation routine and failures will be dynamically displayed. The devices that can be monitored include telemetry, local intersection controllers, and detectors (*27*). After failures are detected they are recorded by the system according to the type and name of failure.

Telemetry devices are diagnosed based on channel loop, master transceiver, and local intersection controller telemetry tests. Failure of the channel loop and master transceiver occurs when a response is not received within 3 seconds on a telemetry channel. Failure of the intersection controller telemetry occurs when valid data are not received for 5 seconds (*27*). Local intersection diagnostics includes several indications for failure. The following is a list of the indications that notify maintenance personnel of intersection controller failures (*27*):

- MMU/CMU flash
- Local flash
- Commanded flash
- Maintenance required
- Cycle fail
- Coordination alarm
- Local free
- Commanded free
- Coordination error
- Preempt
- Alarm 1/Alarm 2.

Detector diagnostics check for detector failure based on maximum presence, minimum presence, excessive counts, and no activity detected. Data supplied by a device that is diagnosed as failed are automatically removed from system computations (*27*).

CHAPTER FOUR

MAINTENANCE ORGANIZATION AND STAFFING

Organization and staffing have a profound effect on traffic signal control systems maintenance management. This chapter presents sample organizational charts for state, county, and city agencies, indicating how they differ among sizes and types of organizations. The chapter also discusses current staffing practices. As summarized from the survey results, staffing tends to increase in proportion to the size of a jurisdiction's population.

ORGANIZATION

The organizational structure of a transportation or traffic agency determines how the work is divided among departments and individuals. An agency may be divided into divisions or departments. This unit may be further divided, depending on the size of the organization, into smaller groups and eventually into individual employee levels or titles. There may be overlaps, however, between divisions and in the case of smaller agencies some divisions are combined, such as maintenance and operations. The overlap can be a cause of confusion if roles are not well defined. For example, one western transportation agency had three departments (traffic engineering, communications, and district maintenance) accessing a ramp metering controller cabinet without providing information to the other departments. This was remedied by developing a set of flow charts, procedures, and check lists for maintenance, which was adopted for use by each of the three departments. In this way the maintenance function was better defined and managed.

Maintenance may be found at various locations in the organizational structure of an agency. In larger agencies it may be its own division, whereas in smaller organizations it may be combined with the traffic operations division. There is no one model that fits all agencies. The location of the maintenance function must be specific to that agency. It is interesting to note that of the surveyed agencies, 42 provided organization charts and no two were alike. Within departments of transportation, the maintenance function was usually located in a separate department. In smaller agencies, the maintenance function was combined with other functions.

Figures 10 through 12 are examples of a state, county, and city maintenance organizational structure, respectively, as provided by the Arizona DOT; Dade County, Florida Public Works; and the City of Omaha, Nebraska. As illustrated by these figures, the maintenance organization becomes less complex as the size of the jurisdiction decreases, although this is not always the case, as some cities have greater populations and larger signal systems than some states. The purpose of these figures is to provide an example of maintenance organization structures that were obtained through the survey.

STAFFING

Survey respondents were asked to indicate the titles, responsibilities, education and licensing, and number of hours assigned to maintenance activities of their maintenance personnel. This chapter provides the results obtained from the survey with respect to personnel.

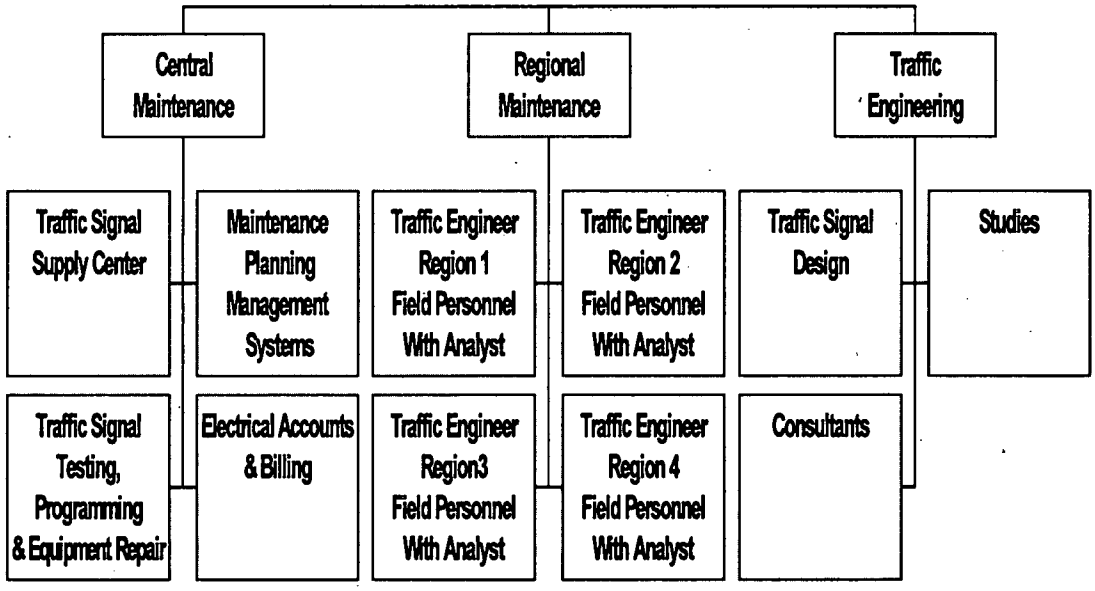

FIGURE 10 Example of state maintenance organization for Arizona DOT.

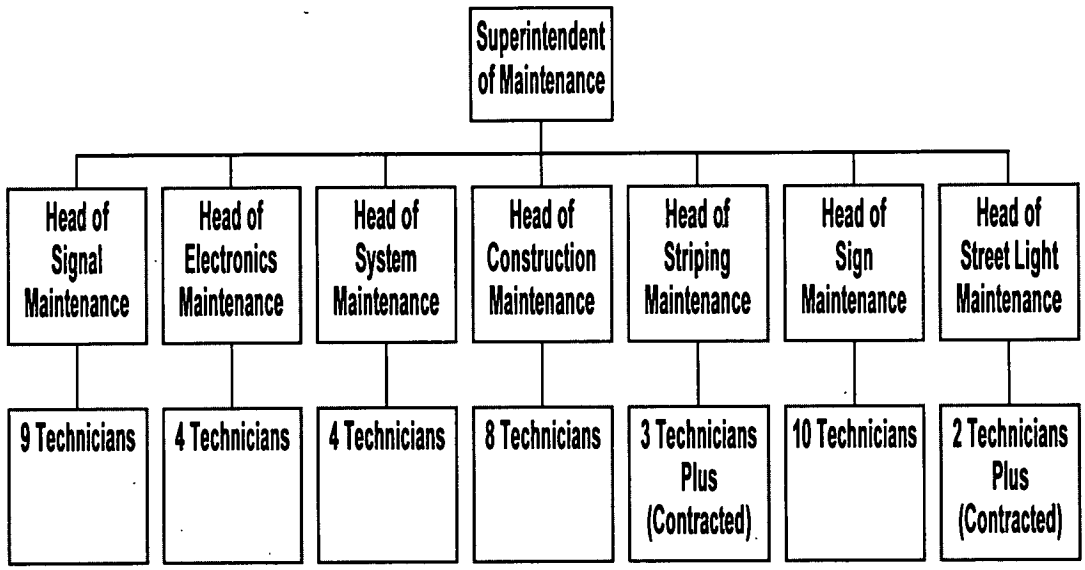

FIGURE 11 Example of county maintenance organization for Dade County, Florida.

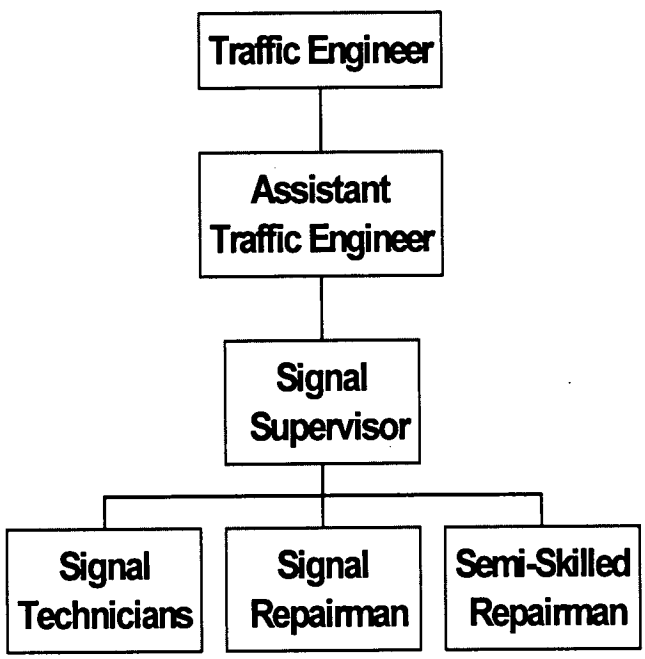

FIGURE 12 Example of city maintenance organization for Omaha, Nebraska.

Depending on the personnel level, the staffing requirements for each vary. For many of the unionized personnel involved in maintenance departments, such as superintendents, supervisors, foremen, electricians, mechanics, specialists, inspectors, and warehouse personnel, typically there are minimum skill level requirements. These unionized positions require journeyman or even master skill levels. Typical journeymen are workers who have completed their apprenticeships and are qualified to work within the trade or craft. Journeymen work for higher level personnel, such as master and are proficient in most of the trade's basic skills. The total length of time at the journeyman level is typically a minimum of 12 years—5 years at the journeyman-helper level and 7 years at the journeyman level. The experience gained at this level leads to promotion to the master level. Master tradesmen are highly skilled workers through significant experience and are qualified to follow their trade independently (i.e., qualified as licensed tradesmen or craftsmen based on passing the license test). They usually are able to supervise the work of others, particularly journeymen.

Other types of personnel found in maintenance departments that are not necessarily unionized are engineers, managers, foremen (depending on the union), supervisor, and the department chief. These personnel usually represent management and many receive management training.

Technicians, helpers or laborers, and equipment operators are other types of personnel who work in maintenance departments. The skill requirements for these positions vary but can be similar to unionized skill levels.

From the survey data, it was determined that personnel titles usually fall into one of the categories listed in Table 2. Most of these individuals work 8-hour shifts and the percent devoted to traffic signal systems ranges from five to 100 percent. Individuals with management responsibilities are at the lower end of this range, whereas engineers, technicians, etc., are at the higher end.

Figures 13 through 15 illustrate the relationship between jurisdictional population and number of maintenance employees per responding agency for those agencies that provided both the number of maintenance employees and jurisdictional population. Each figure represents this relationship for state, county, and city agency types. The data are displayed as solid markers for those agencies who do not contract for maintenance and open markers for those that contract at least some of their maintenance activities. A trendline was plotted for those agencies who do not contract for maintenance. The data points, displayed as open markers, are those agencies that contract at least some of their maintenance activities. A trendline for these data points was not plotted since the data were too diverse.

Figure 13 illustrates the relationship between jurisdictional population and the number of maintenance employees per

TABLE 2

GENERAL PERSONNEL DESCRIPTIONS—TRAFFIC SIGNAL MAINTENANCE

Title	Responsibilities	Avg. Hrs/Shift	Avg. % Time*	Requirements
Chief	In charge of maintenance department, coordinate work schedules of employees	8	68	IMSA certification, 5 years of experience, FCC license, commercial drivers license (CDL), management training
Superintendent	Oversees construction and maintenance, performs project planning, budgeting, scheduling, administration, inventory, etc.	9	43	IMSA certification, FCC license, CDL, journeyman
Supervisor	Supervise crews, schedule work activities, oversee maintenance, operations and construction, issue work orders	8	59	IMSA certification, Master and journeyman, management and computer training, college degree, CDL
Foreman	Supervise shop including inventory, work orders, daily activities	9	71	IMSA certification, FCC license, CDL, journeyman, management training
Manager	General supervision of budget, inventory and purchasing, administrative activities and scheduling	9	22	Advanced management training, P.E., IMSA
Engineer	Management, operations, design, system checks, modifications to timing, supervision of daily activities	8	66	BS in Civil or Electrical Engineering, MS desirable, EIT or P.E., 1–3 years experience, IMSA certification
Electrician	Electrical maintenance, repair of signal equipment, field maintenance, troubleshooting, component repairs	8	74	IMSA certification, journeyman level, or Master level, drivers license, apprenticeship
Technician	Responsive and preventive maintenance, troubleshooting, equipment repair and installation	8	63	IMSA certification, CDL, electronics and electrical training or Associates degree
Mechanic	Troubleshooting, perform repairs and maintenance, installation of equipment	8	63	Controller and conflict monitor training, IMSA certification, Master
Specialist	Test and repair component level electronics, perform cabinet tests, perform all types of field work	8	98	Two year electrical or electronic degree, training in signal work, Master
Helper/Laborer	Perform field repairs, assist technicians	8	48	On-the-job-training, drivers license
Inspector	Supervises contractor work, performs site inspections of equipment operation and installation	8	77	IMSA certification, journeyman, pass written civil service exams
Equipment Operator	Install loops, poles and signs, perform routine maintenance	8	23	Drivers license
Warehouse Personnel	Repair and stock equipment	8	53	IMSA certification, FCC license, journeyman, CDL

*Average percentage of work time devoted to maintenance of traffic signal control systems.

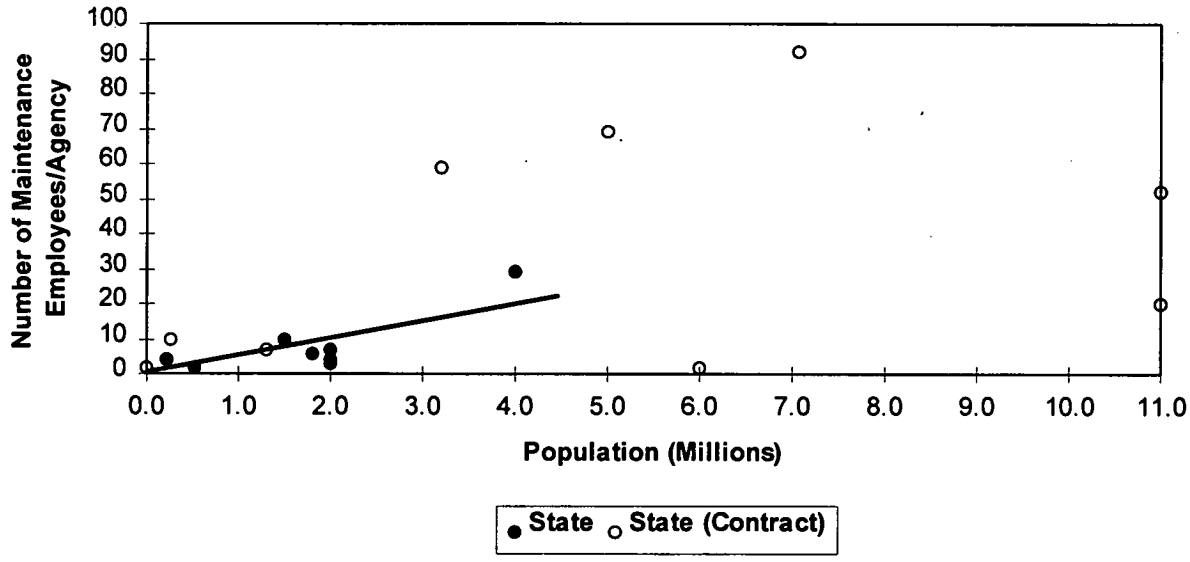

FIGURE 13 Population versus number of state maintenance employees.

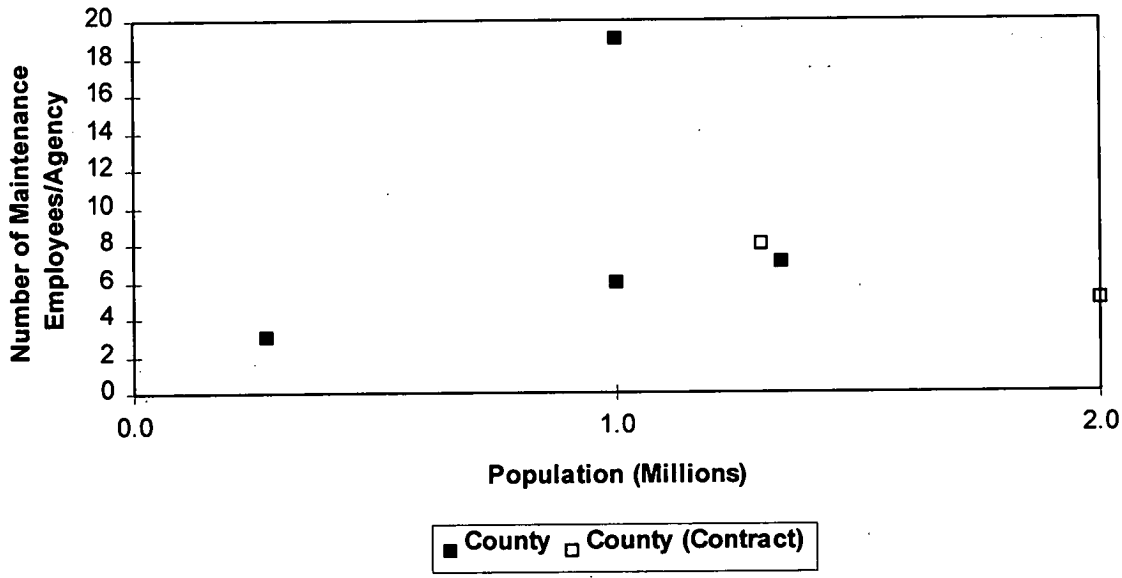

FIGURE 14 Population versus number of county maintenance employees.

state agency. As displayed, an increasing trend is present for those agencies who do not contract for maintenance. One performs all maintenance by contract, 47 percent use only internal staff for maintenance, and 50 percent use both internal staff and contract employees for maintenance. Of those agencies that contract and use internal staff, the mean percent contracted was 42 percent with a minimum of two percent and a maximum of 98 percent.

Figure 14 illustrates the jurisdictional population of the responding county agencies versus the number of maintenance employees per agency. There does not appear to be a trend in the relationship. This may partially be due to the low number of county agencies represented. Of those county agencies who responded (seven total), one performs all maintenance by contract, four use internal staff only, and two use both internal and contract employees. Only one respondent provided a percentage for contract maintenance at 15 percent.

As illustrated in Figure 15, the number of employees appears to increase with an increase in population for city agencies at a rate of 2.6 employees per 100,000 population. This rate seems reasonable. For example, using a rule-of-thumb of one traffic signal per 1,000 population and the above rate, this results in 38 traffic signalized intersections per employee. The example given in the ITE *Traffic Signal Installation and Maintenance Manual* suggests that 31 intersections can be maintained per signal mechanic. The higher rate from the survey data may be due to changes in staffing levels between the two examples. The ITE example was based on a hypothetical case developed in 1988, while the data for this synthesis were based on a survey conducted in 1995.

Approximately 30 percent of the city agencies who responded to the survey use both internal staff and contractor personnel for maintenance of their systems. The mean percentage contracted for these agencies was approximately 15 percent with a minimum of two percent and a maximum of 40 percent. One city agency, not included in the plot, performs all maintenance by contract.

Training

Training needs have changed with changes in technology. Now staff need to have a broader knowledge base including the use of computers. Some agencies in Maryland and Florida have experienced more intense computer training needs by providing opportunities for internal advancement. In these cases, maintenance personnel who did not have computer training during their formal education were promoted to positions where the use of computers was necessary. This lack of formal computer training may be a temporal phenomenon as more children become computer literate during their formal education.

Lack of training can increase risk to an agency if staff do not follow established procedures. Safety to the traveling public can be compromised, especially if maintenance is done by someone who is neither trained nor an employee of the responsible jurisdiction. In some jurisdictions, maintenance has been done by well-meaning citizens who do not follow established lane closure procedures when working in the traveled way. Proper training will protect both the maintainer and the traveling public.

Recently, an I-95 Corridor Coalition (a coalition of 42 transportation agencies located in the 12 states from Virginia to Maine) training needs survey indicated, by all levels of personnel, that their number one training priority was computer training. A survey of 14 state transportation departments (Coalition member agencies) was developed to collect information on the specific training needs of agency managers and of staff within the Coalition. The two-part survey first asked agency managers to identify the overall training needs of their staff as related to 38 ITS technologies deployed in the Corridor and various project functional areas. The second part of the survey asked individual agency employees to identify their training needs.

The agency managers believed that the need for computer training for their staff was so significant that it was ranked in

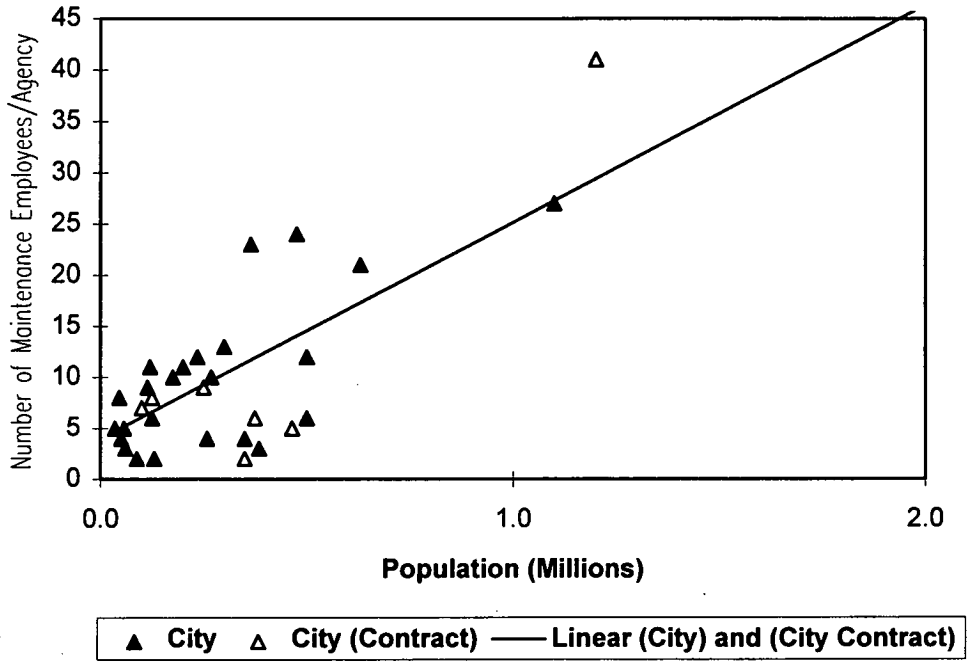

FIGURE 15 Population versus number of city maintenance employees.

the top five of 38 technologies surveyed. A correlation of the two survey parts clearly concluded that computer training needs were the most frequent and most widespread concern of the I-95 Corridor Coalition's member agencies. In comparison, the technologies ranking just below computer training were training needs related to communications systems, incident management, variable message signs, and closed circuit television (*30*).

The survey conducted for this synthesis asked agencies if they had initiated any type of personnel training or retraining programs. Overall, 63 of the 90 respondents answered the question on training. Of those who responded, 71 percent indicated their agency has such personnel training programs. Also, 61 of the 90 respondents answered the question on whether retraining programs have been initiated at their agency; 56 percent indicated that such personnel retraining programs currently exist. Although both surveys indicate that computer training is a much needed item in an effective management system, many of these computer deficiencies can be remedied with relatively intensive and group-oriented training sessions. Perhaps the simplest way to accomplish this is through in-house sessions lasting from 1 to 5 days. Group-oriented in-house training sessions will help agencies to get the most for their efforts in terms of time and cost. Contracted training can also be useful in enhancing particular computer skills relevant to the contract's functions.

The survey data for this question were also divided by type of jurisdiction surveyed: state/province, county, and city. Due to the limited number of Canadian provinces responding to the survey, they were combined with the states' survey results to maintain jurisdictional consistency. According to the state/provincial responses to these survey questions, 63 percent have personnel training programs and 44 percent have personnel retraining programs. Approximately 60 percent and 58 percent of the state/provincial respondents answered the training and retraining survey questions, respectively.

The county data for the training and retraining survey questions showed that 71 percent (or five out of seven) of the agencies each offer personnel training and retraining programs. For each question, two of the nine county representatives did not respond.

According to the city survey data for the training and retraining questions, 77 percent of the city respondents to the training question indicated that their agency offers personnel training programs and 60 percent offer personnel retraining programs. Thirty-two of the 41 survey respondents answered the training question and 31 of 41 answered the retraining question.

The survey results related to maintenance personnel indicated that personnel are hired based on the maintenance needs of an agency with their experience, education, and licensing being commensurate with the job requirements. It was also found that the number of maintenance employees does in fact increase with an increase in jurisdictional population. This result is similar to that reported by ITE. Almost three-fourths of the agencies responding to the survey had a personnel training program; over half had a retraining program.

CHAPTER FIVE

MAINTENANCE PROGRAMMING AND SCHEDULING

This chapter provides information drawn from the survey conducted for this synthesis on how transportation agencies program and schedule maintenance.

The survey recipients were asked what types of maintenance comprise their traffic signal maintenance program, the percentage of each type in the overall program, the schedule for each maintenance type, and to describe the activities performed. This chapter presents the results obtained from the 76 respondents.

Figure 16 illustrates the types of maintenance programs instituted in state, county, and city jurisdictions. Of the 76 cases, 73 individuals provided information on their maintenance programs. The figure illustrates that 90 percent have a preventive maintenance program, 100 percent practice response maintenance, and 77 percent perform design modification. Each bar is divided into the percent of the total that are city, county, and state agencies. There were 36 cities, seven counties, and 30 states responding. One hundred percent of each agency type practices response maintenance; 89 percent of cities, 86 percent of counties, and 86 percent of states have preventive maintenance programs; and 81 percent of cities, 100 percent of counties, and 60 percent of states have design modification programs.

The average or mean percentage of each type of traffic signal maintenance performed by the respondents is illustrated in Figure 17. The overall average percentage of the maintenance program that is preventive was 30 percent. For responsive maintenance, the average percentage of the overall program was 55 percent. The average for design modification was 15 percent.

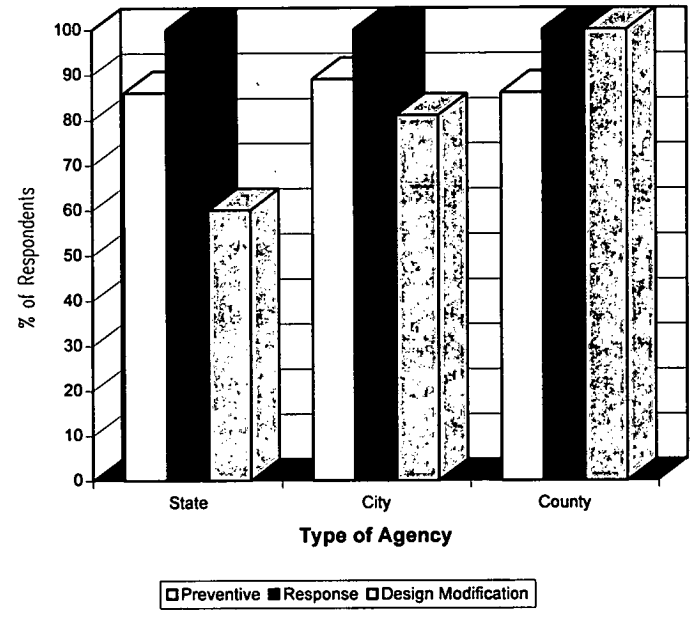

FIGURE 16 Types of maintenance programs by jurisdiction.

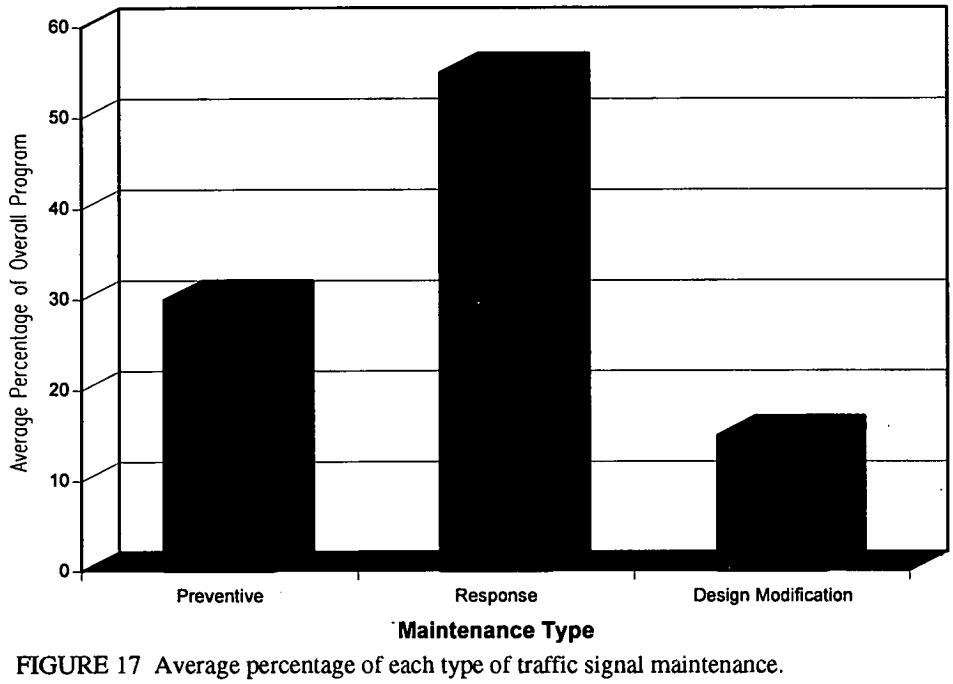

FIGURE 17 Average percentage of each type of traffic signal maintenance.

TABLE 3

DESCRIPTIVE ANALYSIS OF MAINTENANCE PROGRAM TYPES

Maintenance Type	Mean (%)	Standard Deviation (%)	Minimum (%)	Maximum (%)
Overall				
Preventive	30	24	0	90
Response	55	27	0	100
Design Modification	15	18	0	75
Cities				
Preventive	28	20	0	70
Response	54	26	0	98
Design Modification	18	21	0	75
Counties				
Preventive	20	24	5	70
Response	63	26	20	90
Design Modification	17	14	0	40
States				
Preventive	38	28	0	90
Response	53	29	5	100
Design Modification	9	10	0	40

TABLE 4

PREVENTIVE MAINTENANCE ACTIVITIES

Preventive Maintenance Activity	Percent of Respondents
Relamp	44
Inspect and/or replace controllers and cabinets	33
Test conflict monitors	27
Clean signal heads and lenses	23
Generally inspect all equipment	15
Check and/or replace loop detectors	11
General/other	11
Check and/or replace signals	5
Check timing	5
Paint cabinets	5
Check wiring	3
Upgrade components	3
Check hardware	2

A descriptive analysis was performed to determine the mean, standard deviation, and minimum and maximum percentage of the maintenance program for each type of maintenance. Table 3 provides the results of this analysis, presenting statistics for each agency type and overall summary. The table illustrates that the minimum percentage of the overall program for the 76 cases included is zero percent for all maintenance types. The maximum is 100 percent for responsive, 90 percent for preventive, and 75 percent for design modification.

The following sections describe the activities and schedules indicated by the respondents for each type of maintenance program.

Preventive Maintenance

Many different preventive maintenance activities were described as part of the respondents' programs. Table 4 shows the types of activities performed within the preventative maintenance programs and the percentage of the 66 respondents who have these programs that indicated each activity. Many respondents indicated more than one activity, therefore the total percentage is greater than 100. Survey responses also included mention other, no less important, preventive maintenance activities.

One representative from the city of Los Angeles indicated that they are mandated to inspect and test railroad and emergency vehicle preemption signals.

The schedule for preventive maintenance activities varied among the respondents. Figure 18 illustrates the schedule indicated for preventive maintenance. Of the 66 respondents who have a preventive maintenance program, 50 percent indicated that they perform this type of maintenance on an annual basis. Fifteen percent indicated that preventive maintenance is performed twice a year, and 18 percent indicated a variety of schedules.

Response Maintenance

Table 5 illustrates the description of response maintenance activities provided by the respondents who indicated that they have response programs. Of those 72 respondents, 23 percent

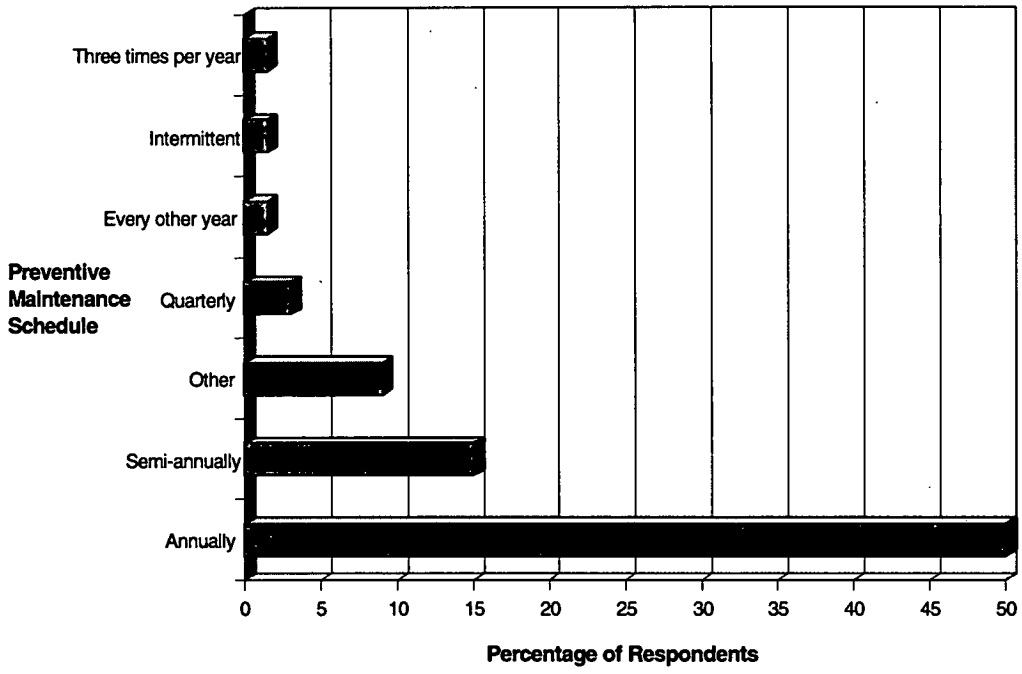

FIGURE 18 Preventive maintenance schedule.

TABLE 5
RESPONSE MAINTENANCE ACTIVITIES

Response Maintenance Activity	Percent of Cases
Trouble/emergency calls	23
Repair failures	18
Burnouts	10
Knockdowns	8
Other	8
As needed	7
Storm outages	4
Accident damage	4
Signal problems	3
Detection problems	1
Field lines	1

indicated that response maintenance is performed as a result of a trouble or an emergency call, 18 percent indicated repair of failures, 10 percent respond to burnouts, eight percent to knockdowns, and 18 percent indicated a variety of activities as illustrated in Table 5.

Response maintenance is performed as needed by 44 percent of the 72 respondents. Figure 19 illustrates the schedules indicated by the respondents for response maintenance activities. Ten percent indicated response maintenance is performed daily, 15 percent respond 24 hours a day, and 7 percent indicated a variety of responses provided in Figure 19. "As needed" can be as often as daily or 24 hours a day or less depending on the occurrence of trouble calls and other emergencies.

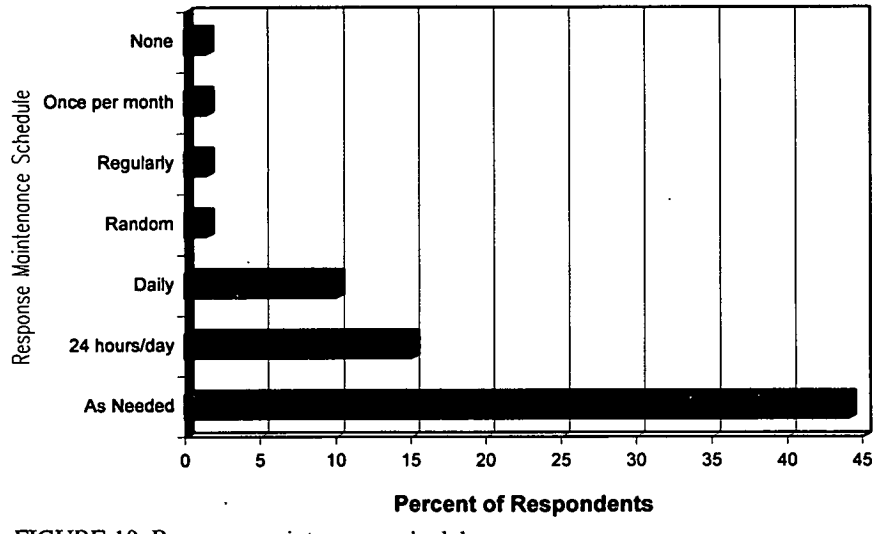

FIGURE 19 Response maintenance schedule.

TABLE 6

AVERAGE RESPONSE TIMES

Day-Time-Condition*	Average Response Time (hours)	Minimum Response Time (hours)	Maximum Response Time (hours)	Number of Responses
Week-Day[a]	2.10	0.17	24	61
Week-Day[b]	2.75	0.17	48	59
Week-Day[c]	1.77	0.17	24	57
Week-Night[a]	1.96	0.25	24	56
Week-Night[b]	1.95	0.25	24	52
Week-Night[c]	2.02	0.25	24	50
Weekend-Day[a]	1.98	0.25	24	61
Weekend-Day[b]	2.01	0.25	24	57
Weekend-Day[c]	2.02	0.25	24	55
Weekend-Night[a]	2.15	0.25	24	53
Weekend-Night[b]	2.12	0.25	24	49
Weekend-Night[c]	2.09	0.25	24	48

*(a) average time when a call is received to when personnel arrive at the site, (b) average time to respond to non-knockdown conditions, and (c) average time to respond to knockdown conditions.

Survey respondents were also asked to identify their response times during the week and weekend, both day and night, in terms of (a) average time when a call is received to when personnel arrive at the site, (b) average time to respond to nonknockdown conditions, and (c) average time to respond to knockdown conditions. Table 6 provides the average time indicated by the respondents, the minimum and maximum indicated, and the number of individuals who provided a response.

Design Modification

Table 7 illustrates the design modification maintenance activities of the 55 respondents who have design modification programs in operation. Of these, 20 percent indicated timing

TABLE 7

DESIGN MODIFICATION MAINTENANCE ACTIVITIES

Design Modification Activity	Percent of Cases
Timing changes	20
Signal upgrades	20
Phasing changes	16
Detector upgrades	8
Controller upgrades	6
Mast arm improvements	6
As requested	6
Intersection upgrades	6
Contractor	3
New installations	7
Other	3
Fiber optic cable installation	1
Emergency upgrades and repairs	5
Design changes	1

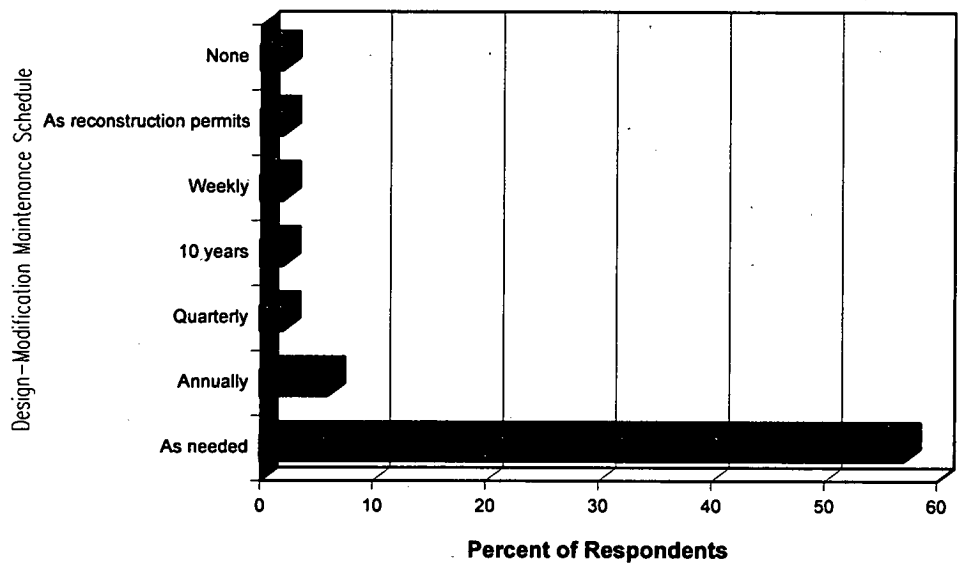

FIGURE 20 Design modification maintenance schedule.

changes were performed, 20 percent cited signal upgrades, 16 percent said phasing changes, eight percent perform detector upgrades, six percent perform mast-arm improvements, six percent cited controller upgrades and six percent said they perform design modifications when requested by the state or by a signal committee. The remaining respondents cited activities including intersection upgrades, new installations, fiber optic cable installation, emergency upgrades, and design changes. Figure 20 illustrates the schedules indicated by respondents who have design modification maintenance included in their programs. Of the 55 respondents who practice design modification, 57 percent perform these activities as needed, five percent annually, two percent do not have a schedule and 10 percent indicated five different schedules.

CHAPTER SIX

ANCILLARY EQUIPMENT AND REPAIR FACILITIES

Certain types of equipment may be required to perform the maintenance functions described in this synthesis. This equipment, which can be categorized as maintenance vehicles, test equipment and tools, and replacement parts and supplies, is usually housed in a centrally located repair shop. For larger agencies, several repair shops may be necessary (*4*). This chapter describes the ancillary equipment and repair facilities that are in current practice.

The ITE *Traffic Signal Installation and Maintenance Manual* provides general guidelines for establishing an equipment inventory or to evaluate an existing inventory. The number of spare parts required will depend on the diversity of the traffic signal system. Adjustments to the number of parts can also be estimated based on historical maintenance records (*4*). For example, some jurisdictions have reported a need for insecticide use in hand holes and cabinets to combat fire ants, bees, and spiders. Table 8 lists of the types of equipment that may be required for a traffic signal system by category and the recommended number of each component. The number and types of equipment will vary depending on the size of the system and the jurisdiction. This table is provided as an example of the information contained in the literature. In addition, some agencies consider notebook or laptop computers as necessary equipment.

During the synthesis study, it was determined that specific maintenance procedures are more applicable for certain components. One person noted that for computer and communication system components, it may be much more practical to have "contract maintenance." Two reasons were cited: 1) it reduces the agency's need for in-house highly skilled technicians and contracts for their services on an as-needed basis, and, 2) it eliminates the agency's need for an inventory of costly spare components.

As previously discussed, each agency usually has a repair shop located equidistant from the furthest points of the jurisdictions. Large agencies, with larger jurisdictional responsibilities, may need to establish a network of repair shops. Layout and size of each agency's repair shop may vary due to

TABLE 8
EQUIPMENT REQUIREMENTS

Equipment Category	Equipment Type	Number
Maintenance vehicles	Bucket truck Platform truck Ladder truck	1 vehicle or 3% of signalized intersections
Test equipment and tools	Multimeter	1 per person
	Oscilloscope	1 per signal engineer
	Controller test fixture (Bench test)	1 vehicle or 2% of signalized intersections
	Suitcase tester	1 per signal engineer
	Detector sensor test equipment	1 per signal mechanic
	Detector test fixture	1 per signal technician
	Frequency generator	1 per signal engineer
	Frequency counter	1 per signal engineer
	Variac	1 per controller test fixture
	Spring tension gauge	1 per signal mechanic
	Small tools	1 per person
	Vacuum cleaner	1 per signal mechanic
	Hardware miscellaneous (electrical tape, level, test lamp, wire, etc.)	As required
	Paint	1 set per signal mechanic
Replacement parts and supplies	Cabinet	1 to 2 of each part (shell, primer, oil, filter, etc.), 4 anchor bolts
	Signal head	2 heads or 5% each (lamp, lens, hood, etc.)
	Mast arms and poles	1 arm/pole or 5% each (mast arm, pole shaft, etc.), 4 anchor bolts
	Span wire	1,000 ft per 100 spans
	Push buttons	2 or 5% (assembly, lamp and lens, post, etc.)
	Detectors	1 to 4 (splice kit, sealant, sensor, etc.)
	Junction boxes and handholes	1 or 2% (covers, etc.)
	Electromechanical controllers	1 to 5 or 2 to 10% (dial assembly, cam, relays, etc.)
	Solid state controllers	1 to 3 or 2 to 5% (load switch, power supply etc.)

differences in staffing, furniture, operating equipment, spare parts, and available building space. The shops are designed for the individual agency's needs. The *Traffic Signal Installation and Maintenance Manual* recommends that each agency consider the following repair shop components (*4*):

- Work station/bench for each signal mechanic
- Work station/office for the supervisor
- Work station/electronic test bench for signal technician
- Work station/office for the signal engineer
- Communication equipment area
- Environmental test area
- Record filing area and/or computer area
- Test fixture areas
- General work area
- Equipment inventory area
- Small spare parts area
- Large spare parts area
- Maintenance and protection of traffic items
- Locker room area.

Additional repair shop components to consider are:

- Prequalifications test area
- Prequalifications storage area
- Employee room
- Environmental test area
- Cabinet assembly area
- Vehicle work area.

The survey respondents were asked to identify those spare parts that their agency inventories and the percentage of each that are deployed. Table 9 presents these results. The table provides the name of the spare part, the average percentage deployed for each part, and the percentage of respondents who indicated that they stock this part. Only those parts indicated by five percent or more of the respondents are presented in Table 9. The spare parts cited by the survey respondents are comparable to those recommended by the *ITE Traffic Signal Installation and Maintenance Manual* discussed previously in this chapter. Appendix D contains more detailed data pertaining to all of the components indicated by the survey respondents.

In another question, survey respondents were asked to briefly describe their repair facilities including equipment and tools. Table 10 presents a summary of the responses to this question. The equipment cited by the survey respondents appears to be comparable to the repair equipment recommended in the *Traffic Signal Installation and Maintenance Manual* discussed previously in this chapter. Appendix E contains more detailed information with respect to the equipment cited by the respondents.

TABLE 9

SPARE PARTS INVENTORIED

Spare Part	Average Percent Deployed	Percent of Respondents
Controllers	12	68
Signal heads	14	36
Conflict monitors	12	33
Detectors	10	33
Cabinets	8	32
Load switches	12	26
Poles	17	22
Cables, conduit, and wire	8	12
Conduit	5	9
Flashers	6	9
Mast arms	7	9
Lamps/bulbs	28	9
Relays	19	8
Modems	7	7
Time clocks	8	7
Wire	3	5
Pedestrian signals	5	5

TABLE 10

REPAIR FACILITIES AND EQUIPMENT

Equipment	Percent of Respondents
Oscilloscopes	41
Conflict monitor tester	29
Controller tester	26
Various meters (ohm, volt, etc.)	22
Computers	18
Multimeter	13
Trucks or vans	13
Load switch tester	12
Bench tester	11
Detector tester	11
EPROM burner	11
Soldering/Desoldering Equipment	11
Electronic component tester	8
Diagnostic equipment	7
Generator	7
Suitcase tester	7
Flasher tester	5
NEMA test board	5
Power supply	5

CHAPTER SEVEN

MAINTENANCE COSTS AND FUNDING

This chapter presents information on funding levels and sources of funding. Levels vary by agency and are dependent on many factors, such as jurisdiction, number of system components, and other societal needs. Sources include state, county, and municipal revenues. Federal funds cannot be used for maintenance, which has resulted in renewed definitions of operations and maintenance.

Of the 76 survey respondents responsible for maintenance of the traffic control systems in their jurisdiction, approximately 45 percent rate their satisfaction with the current level of maintenance as fair or poor. According to a recent ITE/FHWA survey of transportation agencies, 44 percent of agencies surveyed rated their ability to maintain their systems as fair or poor and 22 percent said more funding is needed to effectively operate and maintain existing systems. Lack of funds was indicated as one of the top seven problems faced by public agencies and the outlook for the future is continued shortfalls in funding (*31*).

Federal programs that are contained in the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA), such as Congestion Management and Air Quality (CMAQ), the National Highway Systems (NHS) funds, and Surface Transportation Programs (STP), cannot be used for maintenance of traffic signal systems. However, ISTEA does not place any special conditions, except time limits, on the use of funds for the operations of traffic control systems. Because of the provisions associated with these categories of funds, which have been liberally interpreted, as much "operational support" as possible is included (*31*).

The study conducted for this synthesis reveals that at this time, a change in traditional thinking on funding may be needed. Operations and maintenance definitions for highways and bridges have been clearly defined and often are used for ordinary traffic signal control systems. This approach may be inappropriate for intelligent transportation systems (ITS) such as advanced traffic signal control systems, since many of the traditional maintenance items are, in reality, operational items for ITS. For example, a computerized traffic signal control system cannot operate if either the control computer or field devices are not capable of interaction. Operation of an advanced traffic signal control system depends on the maintenance of traditional signal system components, which can affect whether the advanced system is operational. Thus, funding for an advanced traffic signal control system cannot be deferred as maintenance funding is for traditional highway and bridge traffic signal control systems.

The *ITE Traffic Signal Installation and Maintenance Manual* provides some guidelines for budgeting a maintenance

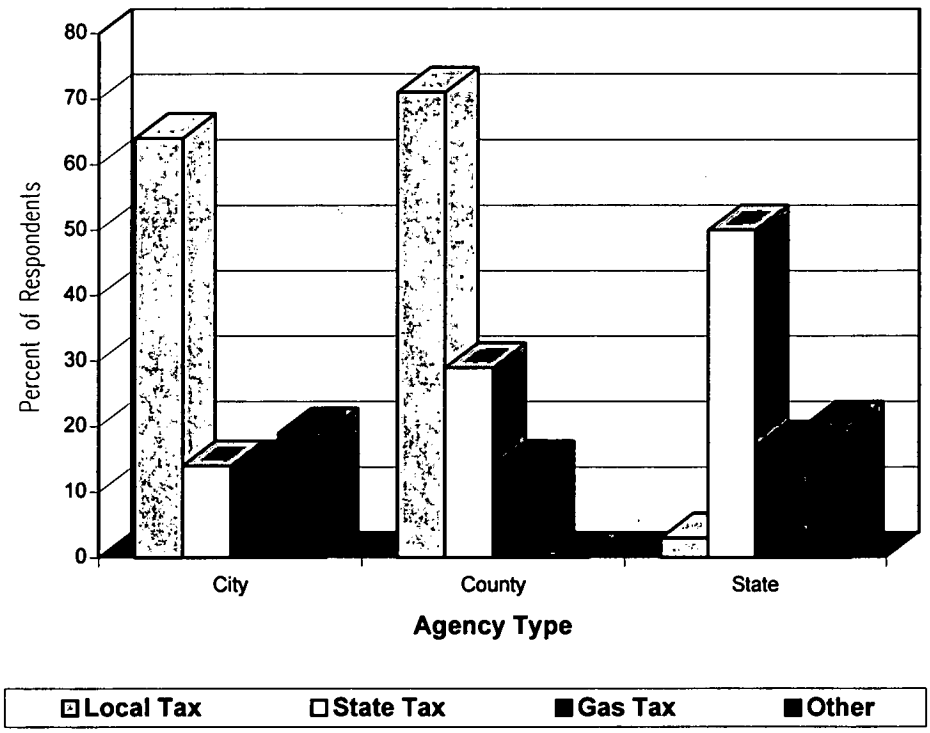

FIGURE 21 1990 maintenance funding sources.

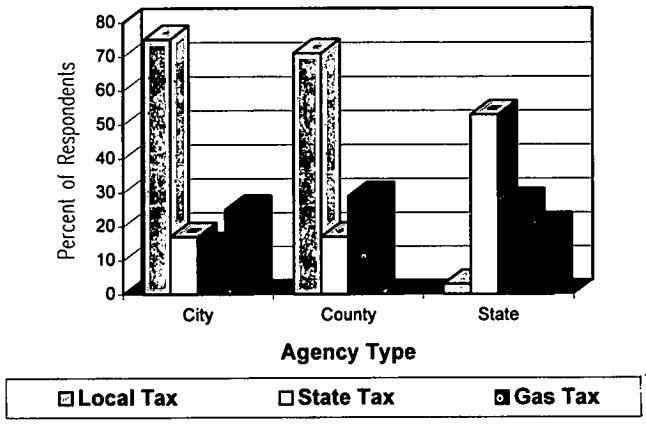

FIGURE 22 1995 maintenance funding sources.

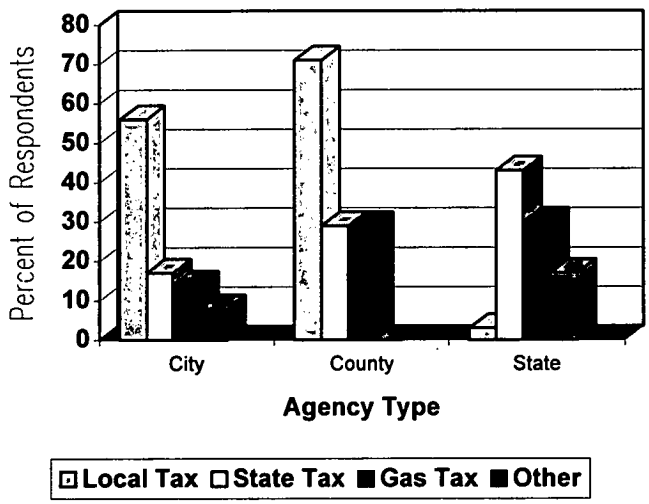

FIGURE 23 2000 projected maintenance funding sources.

management system. The Manual illustrates the method for determining staff salaries, equipment, and spare parts costs.

Based on 31 signalized intersections, the *ITE Traffic Signal Installation and Maintenance Manual* recommends $35,000 for trucks, $4,020 for equipment and tools, $28,000 for personnel, and $60,600 for spare parts. All figures were based on 1986 dollars (*4*).

The survey respondents for this synthesis were asked to identify the sources for their maintenance funding. Figures 21 through 23 illustrate the percentage of respondents who indicated their maintenance funding sources. Each figure represents funding for 1990, 1995, and 2000 respectively. The data are presented by agency type to illustrate that different agencies received their funding from different sources. A more detailed discussion follows each figure.

Figure 21 illustrates the 1990 maintenance funding sources indicated by survey respondents from city, county, and state agencies. As presented, most city and county agencies received their funding in 1990 from local taxes, 61 and 71 percent respectively. Approximately 13 percent of cities received funding from state taxes, 13 percent from gas taxes, and 19 percent from another source not identified by the respondent. State tax funds were received by approximately 29 percent of county agencies and gas tax funds by 13 percent. Half (50 percent) of the state agencies surveyed, as illustrated, received maintenance funding from state taxes, whereas only three percent received funding from local taxes. Approximately 17 percent received funding from the gas tax, 20 percent from other sources.

Figure 22 presents the percentage of respondents from each type of agency that currently (1995) receive maintenance funding from four different sources. As was the case in 1990, the highest number of respondents from city and county agencies received funding from local taxes, 75 and 71 percent respectively. Twenty-five percent of city agency respondents received funding from other sources, 18 percent from state taxes and 13 percent from gas taxes. Nearly 30 percent of county respondents received funding from gas taxes, and 18 percent from state taxes. The majority of state representatives, 52 percent, indicated that their agency received funding from state taxes, 25 percent received funding from gas taxes, 3 percent from local taxes, 20 percent from other sources.

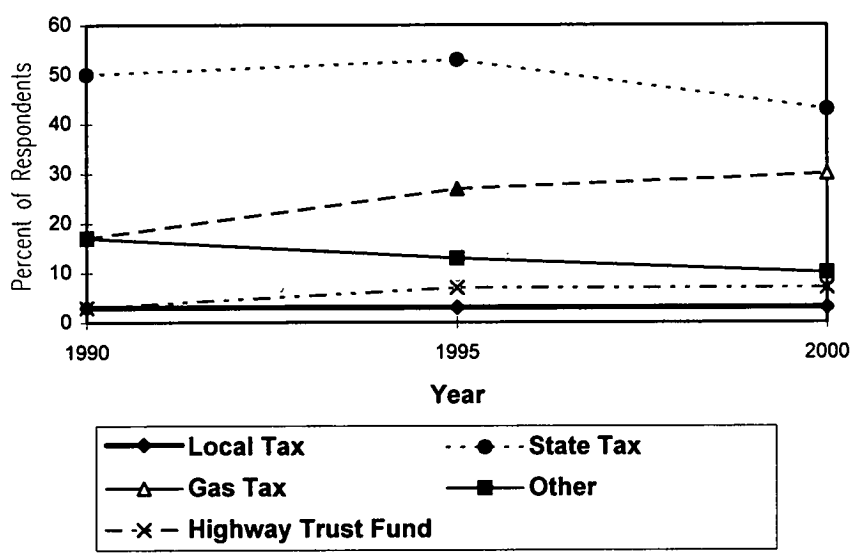

FIGURE 24 State funding trends.

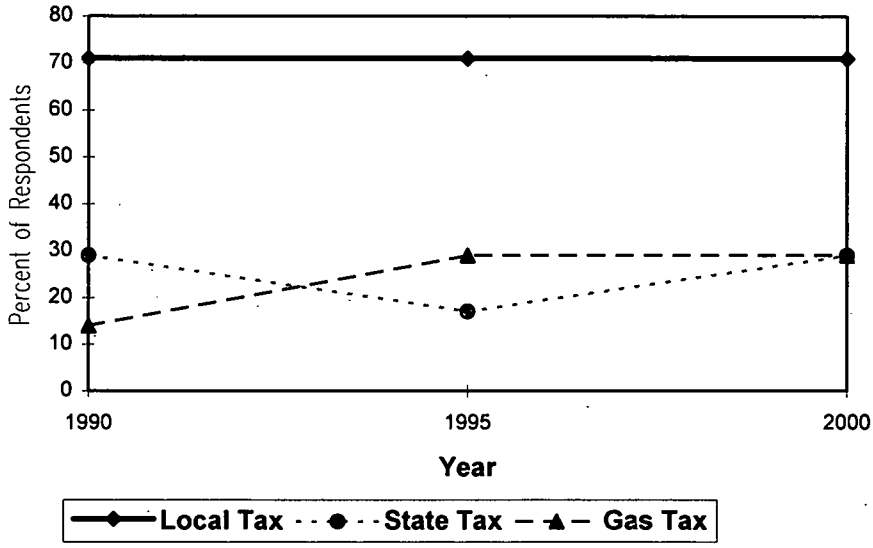

FIGURE 25 County funding trends.

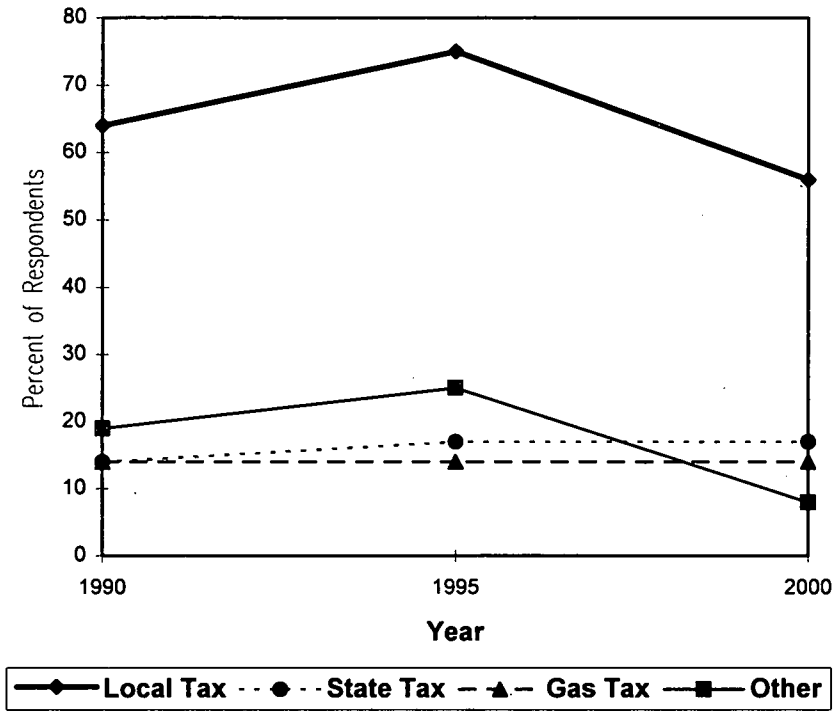

FIGURE 26 City funding trends.

Figure 23 illustrates the projected maintenance funding sources of the survey respondents for the year 2000. As presented, 55 percent of city agency respondents project that maintenance funding will come from local taxes, 17 percent from state taxes, 13 percent from gas taxes, and eight percent from other sources not identified. Approximately 71 percent of county representatives project that maintenance funding will be from local taxes, 29 percent indicated funding from state taxes, and 29 percent from the gas tax. With respect to state respondents, 41 percent indicated state taxes as a source for maintenance, 30 percent indicated gas taxes, 18 percent indicated other sources.

Figures 24 through 26 depict the trends in budget sources for the states, counties, and cities respectively. Each figure illustrates the percent of respondents who indicated each funding source for the years 1990, 1995, and 2000. The purpose of these plots is to establish the trend in maintenance funding sources over the 10-year period. A description of each figure is provided.

Figure 24 depicts the funding trends of state agency respondents. As illustrated, the respondents indicating state taxes increased slightly from 1990 to 1995 and then decreased from 1995 to 2000. Those respondents who cited gas taxes as sources increased over the 10-year period while the percentage who indicated other sources decreased. The percentage of

respondents who indicated the highway trust fund as a source increased slightly from 1990 to 1995 and remained steady to 2000. The percentage indicating local taxes remained constant over the 10-year period.

Figure 25 illustrates the funding trends of county agencies. The same percentage of respondents indicated local taxes as a funding source over the 10-year period. The number of respondents who indicated state taxes as a source decreased from 1990 to 1995 and increased from 1995 to 2000. Respondents citing gas taxes as a source increased from 1990 to 1995 and remained constant from 1995 to 2000.

As illustrated in Figure 26, the percentage of city agency respondents who indicated that their agency's maintenance funding is from local taxes increased in 1995 from 1990 but decreased in 2000. In comparison, the percentage indicating state and gas taxes as a source increased slightly over the 10-year period. Funding sources in the other category, not identified by the respondents, followed the same trend as local taxes.

The purpose of this chapter was to present the funding levels of the survey respondents and the sources of those funds. As illustrated, the levels and sources vary among the different agencies. Local taxes provide the major source for city and county agencies, while state taxes provide the major source for state agencies. It is anticipated that these major sources will be dominant in the year 2000, although gas taxes are expected to provide a larger share of state budgets and local taxes are expected to provide a smaller share of city budgets.

CHAPTER EIGHT

MANAGEMENT

Management of a traffic signal control system encompasses a wide range of activities. It includes management systems, administration, communications and public relations, inventory control, service history and records, fiscal controls, resource sharing, special design considerations for low maintenance and natural disasters, and litigation documentation. This chapter summarizes the management practices of the transportation agencies surveyed.

MAINTENANCE MANAGEMENT SYSTEMS

Maintenance management systems describe how an agency performs and tracks its maintenance activities. Some agencies use advanced software applications to monitor all activities, whereas other agencies perform responsive maintenance as necessary with little emphasis on the management system. Survey respondents were asked to describe their maintenance management systems. Figure 27 illustrates the results obtained from the respondents.

As shown in Figure 27, the most often cited maintenance management system was preventive maintenance (37 percent of the respondents). Computer software applications were indicated by approximately 18 percent of the respondents, and emergency response by 14 percent. Twelve percent indicated that their agency does not have a maintenance management system. All other categories were indicated as less than 10 percent by the respondents. Systems cited in the Other category included inspection programs, departmentwide complaint system, one-person operation, access to proper tools and equipment, and budget allocation and contract bidding.

ADMINISTRATION

In addition to the maintenance management system, administrative matters must be addressed. The survey respondents were asked to identify their agency's administrative practices. Figure 28 shows the distribution of responses. As illustrated, approximately 37 percent of the responding agencies have assigned staff to perform administrative activities. Approximately nine percent indicated they do not have any administration practices. Ten percent indicated that administration varies by district. Items in the other category include computer programs and telephone.

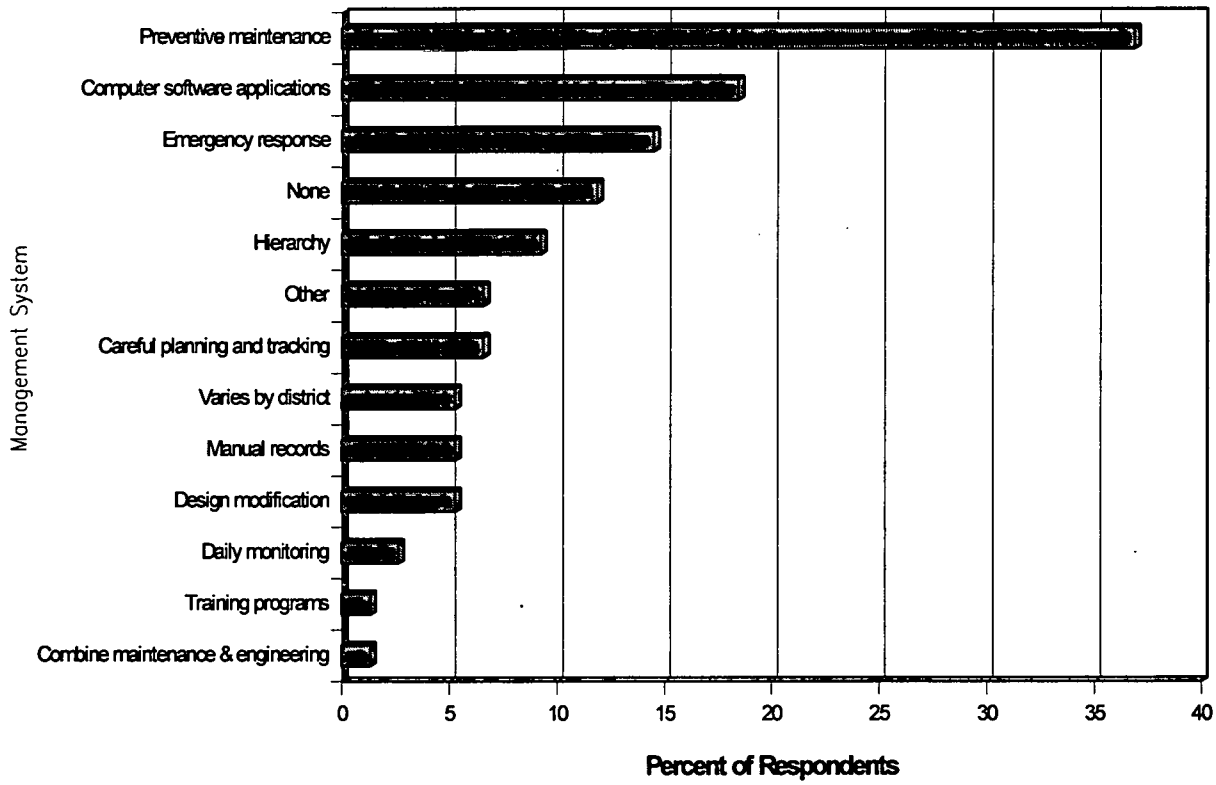

FIGURE 27 Maintenance management systems.

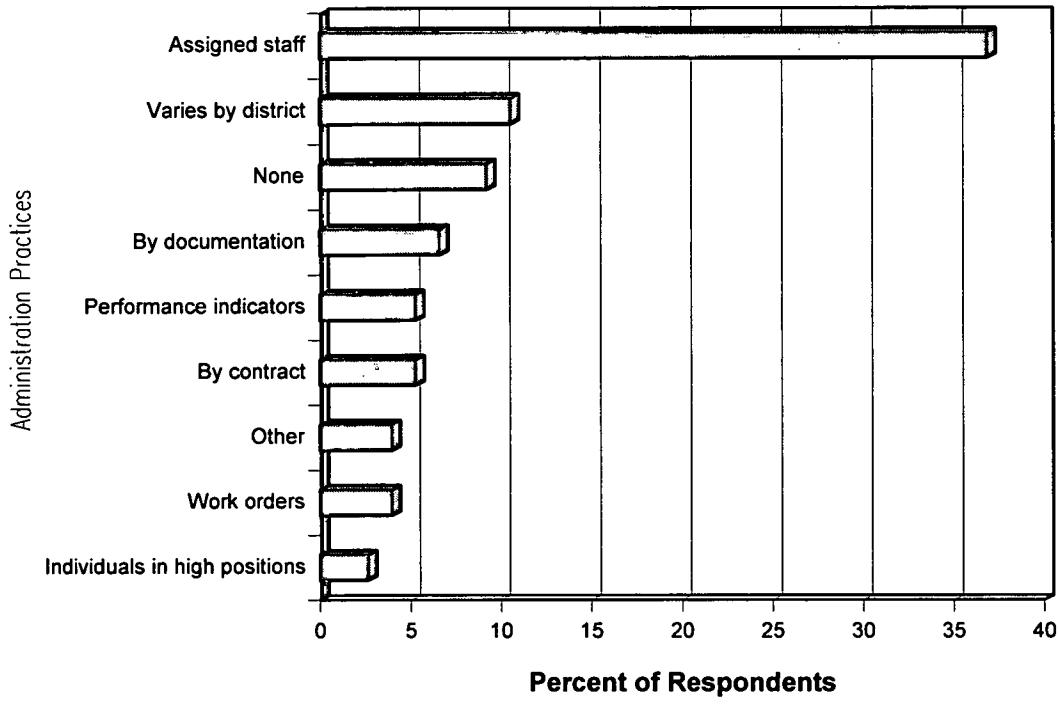

FIGURE 28 Administration practices.

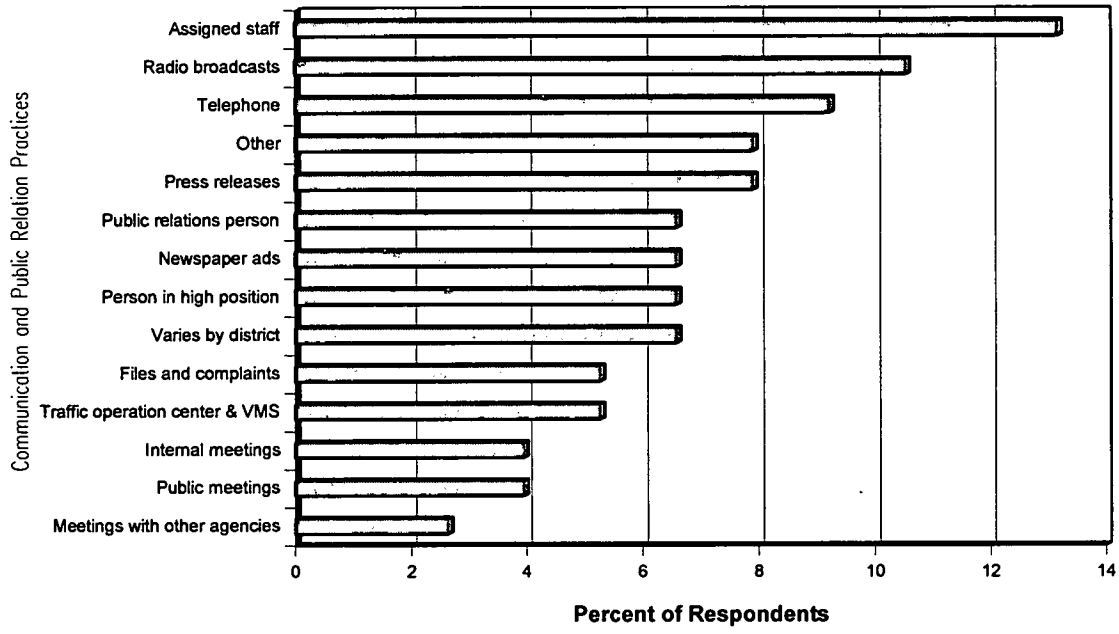

FIGURE 29 Communications and public relations practices.

COMMUNICATION AND PUBLIC RELATIONS

Communications within an agency and between an agency and outside entities is important to a management system. Good relations with the public are also important in the case of a signal system, especially when problems occur. Survey respondents were asked to identify their communications and public relation strategies or practices. Figure 29 illustrates the responses.

As shown in Figure 29, 13 percent have staff assigned to a communications and public relations task, 11 percent broadcast public announcements on the radio, nine percent use the telephone for communication needs, eight percent issue press releases, seven percent have a public relations position within the organization, seven percent use newspaper ads for public announcements, and seven percent have a person in a high position address the public. A total of eleven percent of the respondents conduct meetings to communicate and address

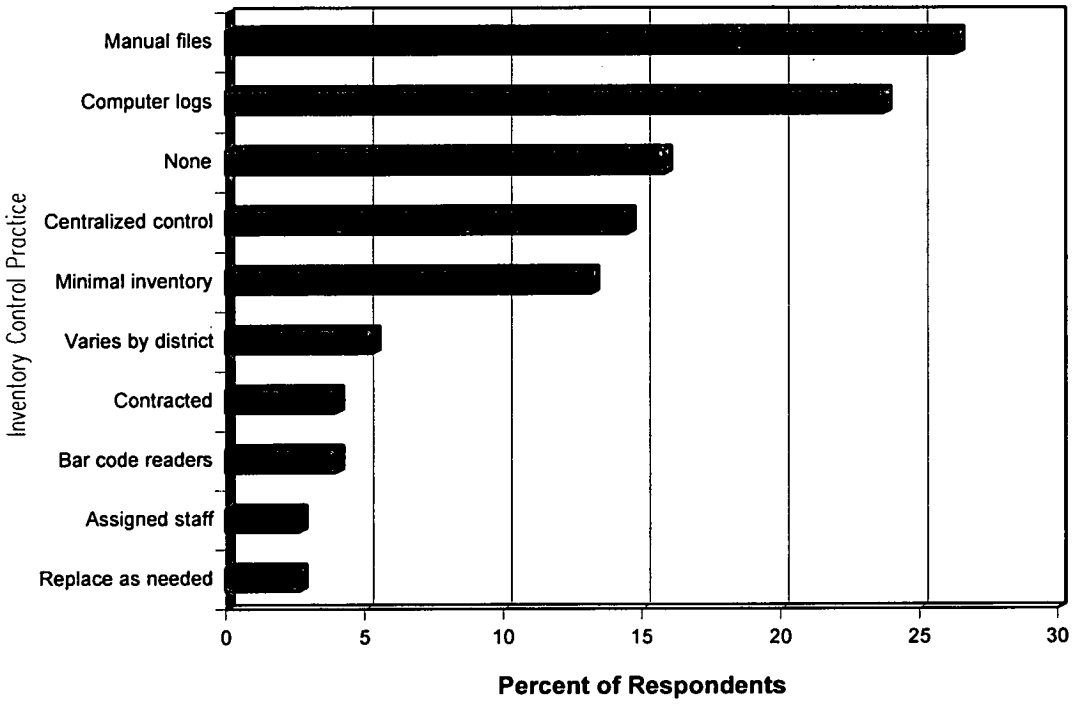

FIGURE 30 Inventory control methods.

public concerns (four percent each for internal and public meetings and three percent hold meetings with external agencies). Five percent use their traffic operations center and variable message signs to communicate within the agency and then to the public. Files and complaints are addressed by five percent to improve communications and public relations. Practices that fell into the "other" category, eight percent, included system communication links, requesting headquarters' assistance when needed, operating a citizen hotline, and using local government officials and the public as resources.

INVENTORY CONTROL

Controlling the amount of spare equipment that is stocked while maintaining a supply of necessary items is important. Some methods of inventory control include paper documentation, regular inventory checks, computerized databases, and bar code systems. Survey respondents were asked to indicate their agency's method of inventory control. Figure 30 presents the results from this survey question.

As shown in Figure 30, 26 percent of the respondents maintain manual or paper logs of spare parts and materials. Computer logs or data bases are used by approximately 24 percent of the respondents whereas nearly 16 percent do not have a method for monitoring their inventory of materials. A further look at those respondents who indicated they have no method for monitoring inventory found that eight are city agencies, two are states, and two are counties.

Approximately 14 percent of the respondents indicated that their agency has a centralized inventory control system where parts and equipment are housed in a central location and are requested from this location on an as-needed basis. The staff at the central location maintains the inventory records. About 13 percent of the respondents indicated that they only inventory the minimal number of spare parts that are needed. This implies that only those parts that the agencies reinstall or replace frequently are stocked and all other parts are ordered or purchased when the need for them arises. Five percent said that inventory practices vary by district, four percent contract for inventory, four percent use bar codes and bar code readers to track equipment and parts, three percent have staff assigned solely to inventory control, and three percent order or purchase parts only when they are needed.

Inventory systems, such as for the INFORM system in Long Island, New York, are intended to provide a list of equipment and related equipment information including description, location, condition, purchase date, dates put in/out of service, quantity on-hand and manufacturer. Another purpose of the system is to track maintenance equipment used (*26*).

SERVICE HISTORY AND RECORDS

It is important for a transportation agency to maintain a history of maintenance activities. This is usually in the form of paper or computerized logs or reports. In addition, timing plans and original drawings are often maintained in archives kept by public agencies. These records can be useful in case of liability charges to provide written proof of proper maintenance activities and for reference during design modification or reconstruction activities. Survey respondents were asked to indicate their agency's service history practices. Figure 31 illustrates the responses provided.

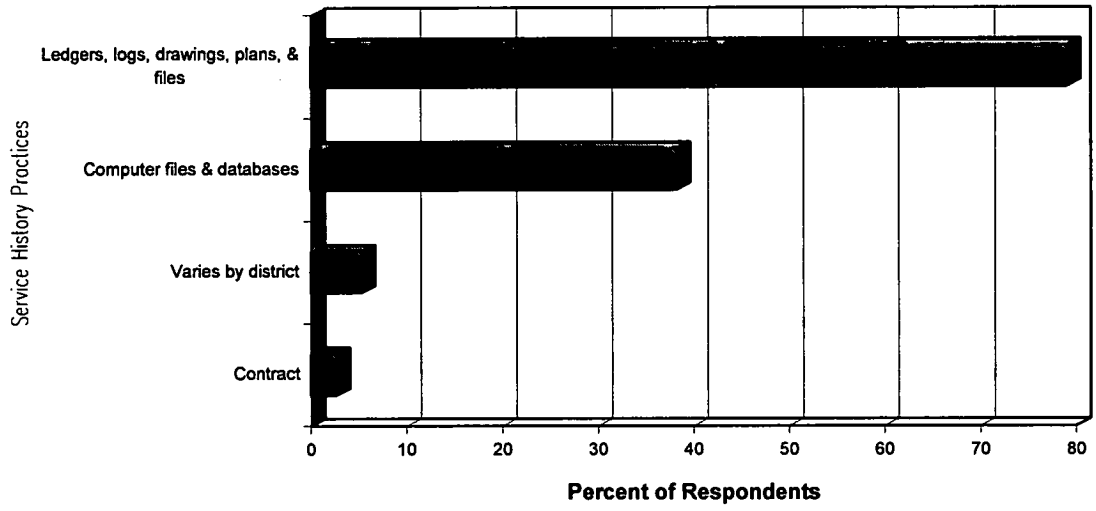

FIGURE 31 Service history and records practices.

Ledgers, logs, drawings, plans, and files are maintained by 79 percent of survey respondents. Approximately 38 percent use computer files and data bases to store service histories and records. Five percent indicated that service history and records vary by district and two percent cited that service histories are maintained by the contractor.

RESOURCE SHARING

Resource sharing can be defined as two or more agencies using the same personnel, equipment, devices, and other resources on a mutually approved schedule. This practice reduces the costs for these resources imposed on the agencies

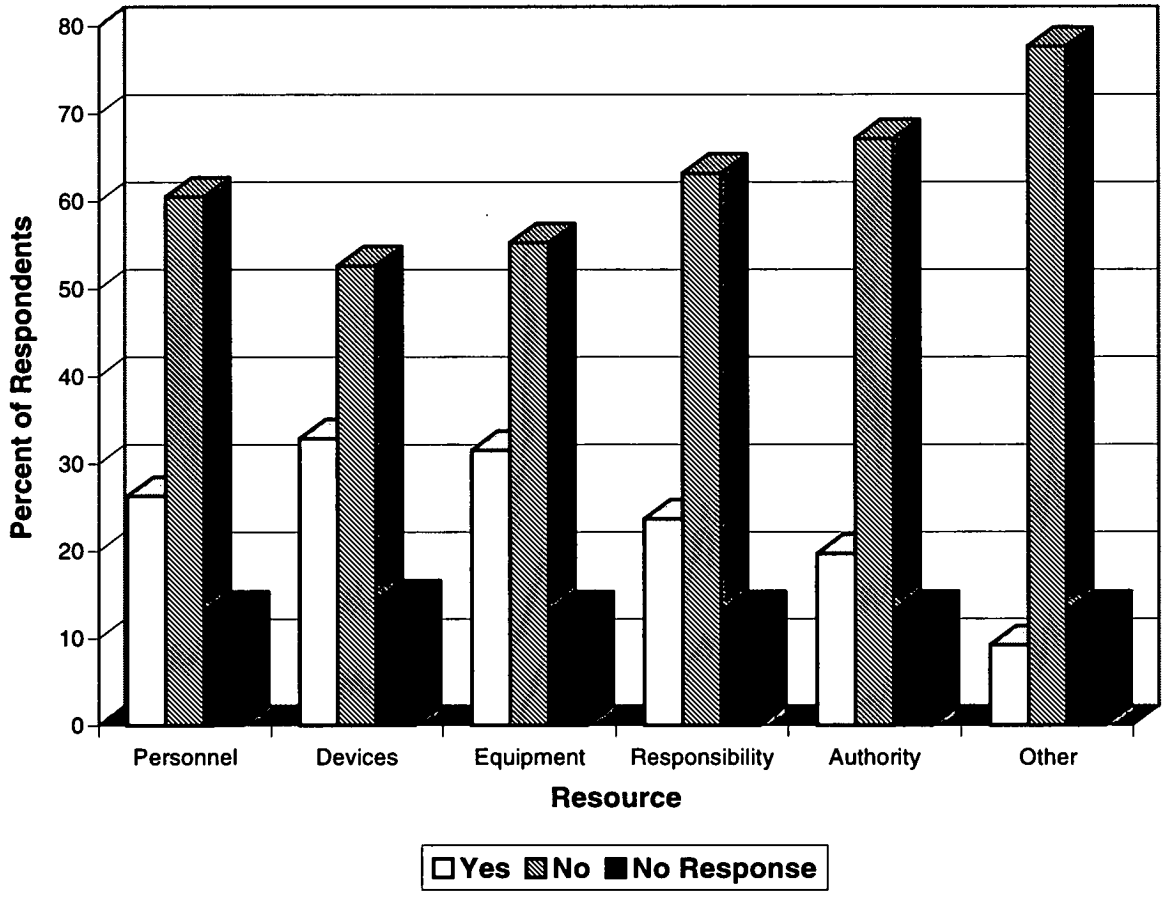

FIGURE 32 Resource sharing.

TABLE 11

RESOURCE SHARING BY AGENCY TYPE

Agency Type	Personnel	Devices	Equipment	Responsibility	Authority	Other
City	County Fire dept. Other cities Other depts. State	County Fire dept. Other cities Other depts. State Telephone Co.	County Fire dept. Other cities Other depts. State Vendors	County Other cities Other depts. State	County Other cities Other depts. Police State	Contractors County Other depts. State
County	—	Other counties	—	—	—	—
State	Cities Districts Local Police	Cities Counties Towns Fire dept. Local	Cities Counties Districts Local	Cities Counties Districts Local	Cities Counties Local	Cities Counties Local
Canadian Provinces	Freeway group	Cities	Cities	—	—	—

TABLE 12

LOW MAINTENANCE DESIGN RESPONSES

Response	Percent of Respondents
Preventive maintenance program	11
Use of strict specifications and standards	21
Signal design	*33*
–Long-life lamps	7
–Mast arms	12
–LEDs	5
–SM–3 hangers	1
–Crypton filled lamps	1
–Aluminum signal heads	1
–Glass lenses	3
–Plastic signal heads	1
–Use equipment with a history of reliability	1
–Use heavy duty lamps	1
Special poles	*18*
–Galvanized	12
–Wood	1
–Quality priming to reduce painting	1
–Use only two types	1
–Use removable pedestals	1
–Use only one type	1
Stainless steel parts	1
Special pull box design	4
–Polymer	1
–Located every 100 feet	1
–Concrete	1
Special cabinet design	*14*
–Aluminum cabinets	7
–Install fans and rear doors on base–mounted cabinets	1
–Clean vacuum and oil doors regularly	1
–Careful location to prevent knockdowns	1
–Specially hinged back panels	1
–Use of only two types of cabinets	1
–Use of 332 cabinets only	1
Special detector design	*18*
–Encased loops	4
–Increased depth of loops	4
Special detector design (continued)	
–Use of magnetic detectors	1
–Motion detectors instead of loops	1
–Use of video detectors	3
–Use of shorter loops	1
–Use pre–formed loops instead of sawed–in loops	1
–Install loops before surfacing roadway	1
Special cable design	*5*
–Conform to IMSA standards	1
–Use underground wiring	3
–Use twisted–pair cable unbroken from controller to controller	1
Controllers	*9*
–Purchase 170s from only two manufacturers	1
–Upgrade to 170s	1
–Upgrade to solid-state	3
–NEMA only	1
–Use microprocessor based equipment	1
–Replacement	1
Other	*20*
–Varies by district	1
–Perform NEMA testing on receipt of equipment	1
–Use Caltrans QPL equipment only	1
–Procure equipment through life-cycle costs	1
–Discuss new designs and accept before implementing	1
–Use AutoCAD	3
–Locate equipment distance from roadway to minimize knockdowns	1
–Experience guiding design modifications to reduce failures	1
–Install lighting protection	1
–Use line and field suppressers	1
–Use interchangeable parts	1
–Perform in–house repair	1
–Upgrade old equipment	1
–Perform in–house construction	1
–Involvement in pre–design and construction	1
–Use high quality materials	1
–Perform proper installation	1

TABLE 13

SPECIAL CONSIDERATIONS FOR NATURAL DISASTERS AND VANDALISM PROTECTION

Special Consideration Response	Percent of Respondents
Signal mounting	6
Higher design speeds	1
Incident or emergency management plans	20
Remote control signs	1
Removable equipment	4
Emergency equipment	4
Elevated controller cabinets	4
Special timing plans	2
Other	*15*
–Cabinet locks	1
–Computer passwords	1
–AASHTO design standards	1
–Stockpile equipment before hurricanes	1
–Design for hurricanes	1
–Use distributed system	1
–Budget for disaster damage	1
–Use plastic cabinet covers and doors in place of aluminum	1
–Stock two spare signals	1
–Case-by-case basis for vandalism	1
–Special domes for CCTV cameras	1
–Portable generators	1
–Lightning protection	1
–Heavy duty equipment	1
–Special cabinet keys and wrenches	1
None	36

and promotes partnerships and good relations between public organizations. Survey respondents were asked to identify whether they share resources such as personnel, devices, responsibility, equipment, authority, or any other resource and with whom. Figure 32 illustrates the percentage of respondents who share each resource, do not share resources, or did not provide a response.

As presented in Figure 32, more than 50 percent of respondents do not share agency resources. Approximately 25 percent share personnel, 31 percent share devices including signals, preemption, surveillance devices, etc., 30 percent share equipment such as controllers, 22 percent share responsibility, 20 percent share authority, and 9 percent share another type of resource. The resources that were cited in the Other category include costs, construction and inspection, information and interagency resources. Approximately 13 percent of the respondents did not provide a response. It was determined from the analysis that approximately 34 percent of the respondents indicated that they share more than one resource with other agencies or organizations.

To determine with whom the respondents are sharing resources, a cross-tabulation of partnered agencies was performed. The results of this analysis are presented in Table 11.

SPECIAL DESIGN CONSIDERATIONS

This section discusses two types of special design considerations: low maintenance and natural disasters and vandalism. Low-maintenance design can reduce the need for maintenance of a system component, thereby reducing costs and time spent on repairs. Special designs for natural disasters and vandalism has the same objectives as low-maintenance designs.

Low-Maintenance Design

Low-maintenance design includes practices and the use of materials or equipment that require little maintenance to operate properly for the expected life of the product. Practices can include preventive maintenance programs; materials can include the use of mast arms for signal displays. "Maintenance experience has shown that certain details and design features can reduce signal maintenance requirements and problems significantly" (*4*). The survey respondents were asked to identify the low-maintenance design practices of their agencies. Table 12 lists the responses and the percentage of individuals corresponding to those answers. Because of the variety of responses, they are categorized by equipment type. Approximately 11 percent of the individuals did not provide a response.

Natural Disasters and Vandalism

Another aspect of maintenance management is special consideration for natural disasters such as hurricanes and tornadoes, and for vandalism. Respondents were asked to indicate the special considerations their agencies implement. Table 13 lists the considerations cited by the respondents. The response and percent of respondents are indicated in the table.

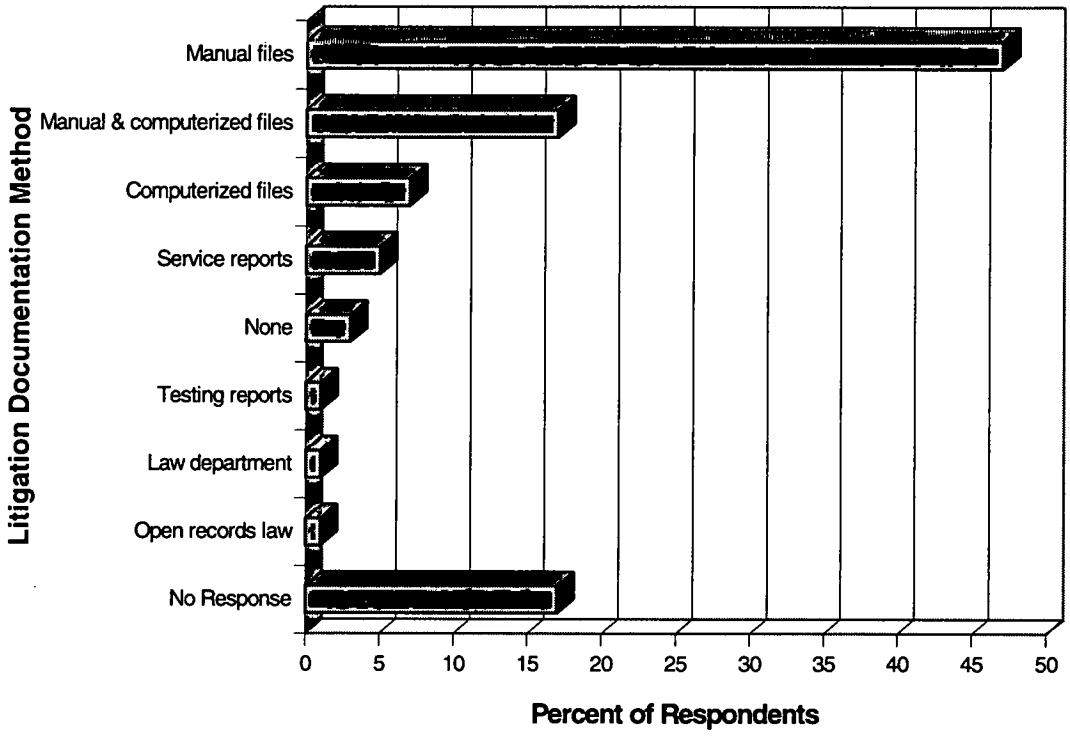

FIGURE 33 Litigation documentation methods.

Approximately 11 percent of the respondents did not indicate any special considerations. Although no respondents mentioned seismic stabilization as a special consideration, it should be mentioned here because federal, state, and local codes and practices are included as part of normal seismic practice. This is especially applicable in the earthquake-prone western United States.

LITIGATION DOCUMENTATION

The final category of maintenance management systems discussed in this chapter is litigation documentation. This involves documentation of all maintenance activities in case of liability lawsuits against the public agencies responsible for maintenance of traffic control equipment. Respondents were asked to indicate the number of pending lawsuits against their agency, if they believe that the number is increasing, and the type of documentation practiced by their agency.

The average number of lawsuits per agency determined through the survey was eight, with a minimum of zero and a maximum of 200. Removing the two highest numbers of law suits, 150 and 200, the average number becomes two lawsuits per agency with a range of zero to 15. The most often cited response (mode) was zero from 45 percent of the respondents. Approximately 20 percent of the respondents did not provide an answer to this question.

Approximately 57 percent of the respondents indicated they believe that the number of lawsuits is not increasing in their jurisdiction. Twenty-eight percent cited that the number of lawsuits is increasing, four percent said they did not know if the number is increasing or decreasing, and 12 percent did not indicate a response.

Figure 33 illustrates the types of litigation documentation used by the survey respondents. As shown, approximately 47 percent have a manual filing system that includes maintenance logs, schedules, completed work orders, plans, and drawings. Seven percent use computerized files and databases and 17 percent use both manual files and computerized files. Four percent indicated that they maintain service reports for liability purposes, three percent said they do not have a system, one percent indicated each of the following: open records law, law department assigned to litigation documentation, and testing records. Approximately 17 percent did not provide a response.

Maintenance management is important to the proper operation of a traffic signal control system. There are several components of maintenance management as presented in this chapter. As discussed, it is important to maintain accurate and complete records, administer the responsibilities to the proper individuals, and to implement special design considerations for low-maintenance and natural disasters to help prevent maintenance overload during times of catastrophe.

CHAPTER NINE

CONCLUSIONS

The purpose of this synthesis was to present the state of the practice in the maintenance management of traffic signal control systems. This was accomplished through an extensive literature review as well as a survey of transportation agencies. The intent of the literature review was to provide descriptions of the available technologies. The survey results were compiled and presented to establish the extent to which transportation agencies are using these technologies.

Maintenance Programs

In summary, all of the transportation agencies surveyed have a response maintenance program in place and on the average it accounts for approximately one-half of their overall maintenance program. Most agencies also practice preventive maintenance, accounting for about one-third of their overall programs. About three-quarters perform design-modification maintenance activities, which accounts for one-sixth of traffic signal control system maintenance programs.

Response Maintenance

Examining the maintenance programs response times further, it was revealed that:

- The maximum time to respond to a trouble call (time when a call is received until personnel arrive at the site) for a knockdown condition was 24 hours. The average response time was approximately 2 hours.
- The maximum response time for nonknockdown condition was 48 hours; however most agencies reported a maximum response time of 24 hours. The overall average response time was approximately 2 hours.

Maintenance Personnel

The number of maintenance personnel, an important component of the maintenance management team, was found to increase as the population of a jurisdiction increased. Excluding those agencies that contract at least part of their maintenance activities, it was determined that, for city and state agencies, the number of maintenance employees generally increases with an increase in population at a rate of approximately 2.6 and 2.3 per 100,000 persons, respectively. Using a rule-of-thumb of one traffic signal per 1,000 population and the above rates, this results in 38 to 43 traffic signalized intersections per employee.

Resource Sharing

Most transportation agencies surveyed do not share resources such as personnel, devices, equipment, responsibility, or authority with other agencies.

The cities that share resources generally coordinate with county agencies, local fire and police departments, utility companies, vendors, and other cities or departments.

The counties surveyed that share resources share only devices with other counties, although cities indicated that the resources they share with counties included personnel, devices, equipment, responsibility, and authority.

State agencies share all types of resources with cities, districts, local fire and police departments, and towns.

One Canadian province shares personnel with the freeway group, and devices and equipment with cities within their jurisdiction.

Procurement

With respect to procurement of equipment, parts, and services, most agencies surveyed use the low-bid process. Although many of them cited that there are legal issues associated with this process, it is generally required by the city, county, or state. A small percentage of agencies that contract some of their maintenance activities use prequalification procurement with the low-bid process.

Budgets and Funding

Budgets and funding are also important components of the maintenance management system.

- County agencies appear to have larger budgets for equipment than states and cities.
- For contractor services, cities have the highest budget.
- For personnel and spare parts, the mean budget increases from cities to counties to states.

The sources of funding for all agencies is generally from taxes such as local, state, and gas taxes.

- Most cities and counties were found to receive funding from local taxes whereas most state agencies' funding is from state taxes.
- Fewer city agencies believe that funding will be from local taxes in the year 2000 than in 1990 or 1995.
- Similarly, fewer state agencies indicated funding would be from state taxes in 2000 than in 1990 or 1995.

• More county agencies project more funding from gas and state taxes in 2000 than in previous years.

Liability

Liability and litigation are important issues faced by many transportation agencies.

• Slightly more than half of the agencies surveyed do not believe that lawsuits are increasing.
• Nearly half of the respondents indicated that no lawsuits are currently pending against their agencies.
• The average number of lawsuits, for those agencies with pending lawsuits was two per agency.

Management Systems

In managing traffic signal systems:

• Half of the agencies surveyed use a paper filing system and have not yet implemented a computerized system.
• Only 18 percent indicated they use computerized filing systems or data bases for at least some of their records.
• Many types of software are available for management, scheduling, administration, inventory control, and record keeping.

It is projected that more and more agencies will convert to computerized techniques in the near future.

Summary

Good maintenance management practices are crucial to the proper operation of traffic signal control systems in a time when funds and resources are limited but the number of signals and systems are ever-increasing. The objective of maintenance is to keep systems and components operating as they were intended to operate. Collecting sufficient data to identify system weak points and managing the activities required to achieve this goal are essential. Many tools are available to aid in this process. Transportation agencies that incorporate these tools into the management of their maintenance systems will improve the reliability and efficiency of their systems.

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APPENDIX A

Survey Instrument

TRANSPORTATION RESEARCH BOARD (TRB)
NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
Project 20-5, Topic 27-11
Traffic Signal Control Systems Maintenance Management Practices Questionnaire

Name of Respondent:

Agency:
Title:

Telephone No.:

FAX:

Instructions

We would like to collect information from your agency on the maintenance management practices employed for traffic signal control systems in your jurisdiction. The information will be used to develop a synthesis report on "Traffic Signal Control Systems Maintenance Management Practices." A copy of our report outline is attached.

The purpose of this survey is to increase the state-of-the-practice in traffic signal control system maintenance management. This synthesis will be of direct benefit to agencies and contractors in the maintenance of their systems.

This questionnaire should be completed by that person(s) with direct responsibilities for either (a) maintaining traffic signal control systems by in-house staff; or (b) managing contractors hired by the agency to perform maintenance. Please answer as many of the following questions as possible. Attach additional sheets if necessary. Also, please provide copies of any supporting data or reports. Send your completed questionnaire and supporting documentation to:

Walter H. Kraft
PB Farradyne Inc.
One Penn Plaza
New York, NY 11019

If you have any questions, please contact Walter Kraft at (212)465-5724 or Janet Ricci at (212)465-5404.

WE WOULD APPRECIATE YOUR RESPONSE

1. How many signalized intersections are you responsible for maintaining by system?

System (i.e. each independent system)	Number of Intersections	Type of Controller (i.e. NEMA 170, etc.)	Type of Control Field	Central	Other*

*Please provide a brief description.

2. What other devices are part of your traffic signal control system (i.e. CCTV, HAR, VMS, preemption, Global Positioning, handheld devices, etc.)

3. Please describe your maintenance management practices as they apply to each of the following categories.
   a. Maintenance management system

b. Administration

c. Communication and public relations

d. Inventory control

e. Service history and records

4.a. What are your annual costs for maintenance? Please include a cost breakdown for each of the following.

Item	Budget 1995	Budget 1990	Budget 2000 (Predicted)
Personnel			

Equipment			
Spare parts			
Contractors			
Other			

b. How is your maintenance funded?

Source	1995	1990	2000 (Predicted)
a. Local Taxes			
b. State Taxes			
c. Special Tax*			
d. Other*			

* Please define

5. Indicate your satisfaction with your current level of maintenance.
   - o Good -able to maintain at a level that allows the systems to achieve most of their potential
   - o Fair -only able to maintain at a level to achieve a portion of their potential
   - o Poor -not able to maintain these systems at a satisfactory level

6. Do you participate in resource sharing (joint use of devices, personnel, etc.)? Please specify resources you "share" and with what agencies/companies.

Resource Shared	Agency/Company shared with	Comments
Devices		
Personnel		
Equipment		
Authority		
Responsibility		
Other (please specify)		

7. What practices do you use for low maintenance design?

8. What special considerations do you use for natural and other disasters (hurricane, flood, earthquake, crime, etc.)

9. The following questions pertain to risk and liability with respect to traffic signals.

   a. How many lawsuits involving traffic signals have been brought against your jurisdiction in the last year?
   b. Is the number of lawsuits increasing? o Y o N
   c. Explain your documentation for potential litigation.

10. Please describe your maintenance organization. Please sketch or enclose an organizational chart.

11a. How is your maintenance performed? Please check the appropriate box.
By internal staff only o
By contract only o
By internal staff and contract o
Percentage contracted ?

b. If you contract out, please send us a copy of your latest contract.

12a. What types of maintenance programs do you have in operation? Briefly describe each program.

Maintenance Program	Yes/No	Percentage of Total Maintenance (%)	Description	Schedule
Preventative	oY oN			
Responsive/ Emergency	oY oN			
Design Modification	oY oN			
Other (Please Specify)	oY oN			

Please attach supporting material

b. Please provide your average response times for your past year of record.

Year _____

Response Time

	a	b	c
Weekend Day, hour__to__ Night, hour__to__			

a = average time when call is received to when personnel get to site
b = average time to respond to non-knockdown condition
c = average time to respond to knockdown condition

13. How many individuals are employed to maintain your traffic signal control system(s)?

In the following table, please list the title, responsibilities, extent of training, and skill levels for each of these people. Also indicate the shift they work (# of hours per day), their responsibilities other than maintenance of traffic signal control systems, and the percentage of their time (or hours per week) devoted to control systems.

Title/Position of each Employee	Responsibilities	Training, License(s) Requirements, and Skill Level	Shift (include # of hours)	% Time Devoted to Control Systems

14a. Have you initiated any type of personnel recruitment or retention (training or retraining) programs? Please describe and enclose copies of your training materials.

Program	Yes/No	Description
Recruitment	o Y o N	
Retention • Training x Retraining	 o Y o N o Y o N	
Other (Please specify)	o Y o N	

b. How do you rate your ability to attract and retain qualified technicians? (circle one)

GOOD FAIR POOR

15a. What procurement processes do you use for traffic signal and/or systems? Please provide samples.

Process	Yes	No	Description/Comments
Low Bid			
Facilities Management			
Life Cycle Costs			
Design Build			
Privatization			
Prequalification			
Other (Please specify)			

b. What legal issues do you associate with the procurement process?

16. What percentage of spare parts do you inventory? Please indicate the part and percentage of total deployed in the following table.

Part	Percent of total deployed (i.e. 5% controllers)

17. What is the population of your jurisdiction?

18. Please describe your repair facilities including your diagnostics tools.

19. Please add any other comment you think we should be aware of.

Please send any manuals, photos, and organizational charts that are instrumental in illustrating your maintenance practices.

Thank you for your valuable assistance.

APPENDIX B

Survey Results

This section provides general results from the survey data. The survey instrument provided in Appendix A was mailed to a DOT traffic engineer in each state, to 93 city and county representatives, and to nine Canadian provinces for a total of 152 surveys. At least one city or county was chosen from each state based on population. Of the 152 surveys mailed to the transportation agencies, 90 responses were received for a response rate of 59 percent. Survey respondents by agency type are shown below.

Agency Type	*Number of Respondents*	*Percent of Total Respondents*
City	41	45.6
County	9	10.0
State	37	41.1
Canadian Province	3	3.3
Total	90	100

Of the 90 individuals who responded to the survey, 77 indicated that they are responsible for maintaining the traffic signal control systems in their jurisdictions. All of the survey results presented in this synthesis are based on a percentage of these 77 respondents, who represent 38 city agencies, seven counties, 30 states, and two Canadian provinces.

The respondents were asked to identify the number of systems maintained by their agency and the number of intersections per system. The average number of systems maintained by a responding agency is 12 systems with a minimum of 0 and a maximum of 300. Agencies indicating zero systems maintain only isolated intersections. The average number of signals per system was 206 with a minimum of two and a maximum of 1611 signals.

A list of the survey respondents is shown below:

ADA County Highway District, Boise, Idaho
Agency of Transportation, Vermont
Bureau of Traffic Engineering, Richmond, Virginia
City & County of Honolulu, Hawaii
City of Albuquerque, New Mexico
City of Bangor, Maine
City of Columbia, South Carolina
City of Concord, New Hampshire
City of Irvine, California
City of Minneapolis, Minnesota
City of Montgomery, Alabama
City of Norfolk, Virginia
City of Oklahoma City, Oklahoma
City of Omaha, Nebraska
City of Phoenix, Arizona
City of San Antonio, Texas
City of Sioux Falls, Iowa
City of Trenton, New Jersey
City of Tulsa, Oklahoma
City of Wichita, Kansas
Department of Engineering, City of Newark, New Jersey
Department of Public Works & Transportation, Rockville, Maryland
Department of Public Works, City of Louisville, Kentucky
Department of Public Works, Milwaukee, Wisconsin
Department of Public Works, Nassau County, New York
Department of Transportation—Signals, Washington
Department of Transportation and Public Facilities, Alaska
Department of Transportation, Arizona
Department of Transportation, Charlotte, North Carolina
Department of Transportation, City of Bellevue, Washington
Department of Transportation, City of New York, New York
Department of Transportation, Connecticut
Department of Transportation, Georgia
Department of Transportation, Iowa
Department of Transportation, Kansas
Department of Transportation, Maine
Department of Transportation, Minnesota
Department of Transportation, Mississippi
Department of Transportation, New Hampshire
Department of Transportation, New Jersey
Department of Transportation, New York
Department of Transportation, North Carolina
Department of Transportation, North Dakota
Department of Transportation, Ohio
Department of Transportation, Oklahoma
Department of Transportation, Texas
Department of Transportation, Virginia
Department of Transportation, West Virginia
Department of Transportation, Wisconsin
Department of Transportation, Wyoming
Department of Transportation, Central Bureau of Operations, Illinois
Department of Transportation, Maintenance Division, Tennessee
Engineering Department, City of Bismarck, North Dakota
Highway & Transportation Department, Missouri
Highway Department, Massachusetts

Highway Safety, Highlands County, Florida
Maint. and Traffic Branch, Fredericton, New Brunswick, Canada
Metropolitan Government, Department of Public Works, Nashville, Tennessee
MetroTransportation, Municipality of Toronto, Ontario, Canada
Ministry of Transportation, Ontario, Canada
MTA, Los Angeles, California
MTMC/Transportation Engineering Agency, Newport News, Virginia
Municipality of Anchorage, Alaska
Office of Transportation, City of Portland, Oregon
Public Works Agency, City of Santa Ana, California
Public Works Department, City of Little Rock, Arkansas
Public Works Department, Nashville, Tennessee
Public Works Department, Rapid City, South Dakota
Public Works, Dade County, Florida
Regional Council of Governments, Denver, Colorado
State Highway & Transportation Department, Arkansas
Traffic Control, Department of Engineering, Pittsburgh, Pennsylvania
Traffic Engineering Division, City of Charleston, West Virginia
Traffic Signal/Maintenance, City of Wichita, Kansas
Transportation and Utilities, Alberta, Canada
Transportation Department, Idaho
Transportation Division, City of Hartford, Connecticut
Transportation Operations, City of Topeka, Kansas
Turnpike Authority, New Jersey

APPENDIX C

Preventive Maintenance Checklist

TABLE C.1

PREVENTIVE MAINTENANCE CHECKLIST (1)*=

TASK	Recommended Interval: MONTHS 3	6	12	YEARS 2 to 5
Cabinet (per unit)				
a. lubricate hinges and lock				x
b. clean filters			x	
c. replace filters				x
d. check weather proof seal (gasket)			x	
e. check anchor bolts				x
f. check for water accumulation and duct sealant				x
g. check ground rod clamp and wire			x	
h. check wiring schematics and records			x	
i. check operation of fan and heater		x		
j. check radio interference filter and lightning arrester				x
k. check circuit breaker			x	
l. check ground fault receptacle		x		
m. measure voltages at service inputs in cabinet			x	
n. check and record current being drawn			x	

(Continued)

*Giblin, J.M., W.H. Kraft, J. Rudden and R. Sands, *Traffic Signal Installation and Maintenance Manual*, Institute of Transportation Engineers, Prentice Hall, New Jersey (1989).

=The preventive maintenance activities presented in this table are only to be considered by an agency when developing their own individual maintenance program. Actual preventive maintenance tasks and corresponding intervals will vary by agency based on local conditions and should be predicated on the equipment manufacturers' recommendations as well as the experience of the maintaining agency.

TABLE C.1 (CONTINUED)

TASK	Recommended Interval: MONTHS 3	6	12	YEARS 2 to 5
a. repaint exterior (if originally painted)				x
b. snow removal			as necessary	
Signal Heads (per unit)				
a. clean lenses, signs, and reflectors			x	
b. replace lamps				x
c. check alignment			x	
d. check for the wear on the span wire, signal wire, and mechanical hardware (clevis pins, clamps)			x	
e. check mast arms, free swinging signals; check clevis and chain			x	
f. check for cracks and rust in the hardware			x	
g. check for bent hoods, wing nuts, hinges			x	
h. replace substandard parts			x	
i. replace defective lenses and reflectors			x	
j. check locking ring (surface), install proper locking devices as required			x	
k. check condition of back plates (if used)			x	

(Continued)

*Giblin, J.M., W.H. Kraft, J. Rudden and R. Sands, *Traffic Signal Installation and Maintenance Manual*, Institute of Transportation Engineers, Prentice Hall, New Jersey (1989).

=The preventive maintenance activities presented in this table are only to be considered by an agency when developing their own individual maintenance program. Actual preventive maintenance tasks and corresponding intervals will vary by agency based on local conditions and should be predicated on the equipment manufacturers' recommendations as well as the experience of the maintaining agency.

TABLE C.1 (CONTINUED)

TASK	Recommended Interval: MONTHS 3	6	12	YEARS 2 to 5
a. repaint exterior of signal (if originally painted)				x
b. perform nighttime check for visibility			x	
Mast Arms and Poles (per unit)				
a. inspect for rust and spot paint as required			x	
b. inspect welded joints for rust and cracks at arm/upright location and at base plate			x	
c. inspect anchor bolts for rust and tightness			x	
d. inspect horizontal and vertical angle of the arm			x	
e. repaint exterior (if originally painted)				x
Span Wire and Bolts (per unit)				
a. inspect poles			x	
b. check span wire			x	
c. check clamps and hardware			x	
d. check guy wire, anchors, and guards			x	

(Continued)

*Giblin, J.M., W.H. Kraft, J. Rudden and R. Sands, *Traffic Signal Installation and Maintenance Manual*, Institute of Transportation Engineers, Prentice Hall, New Jersey (1989).

=The preventive maintenance activities presented in this table are only to be considered by an agency when developing their own individual maintenance program. Actual preventive maintenance tasks and corresponding intervals will vary by agency based on local conditions and should be predicated on the equipment manufacturers' recommendations as well as the experience of the maintaining agency.

TABLE C.1 (CONTINUED)

TASK	Recommended Interval: MONTHS 3	6	12	YEARS 2 to 5
Push Buttons (per unit)				
a. check and actuate push buttons on each end of actuated crosswalks and visually verify pedestrian signal operation; verify timing		x		
b. check push button lamp (if one exists) for operation			x	
c. check push button signs, clean or replace I necessary			x	
d. check push button sign alignment)			x	
Detectors (per approach)				
Sensors				
a. visually inspect roadway along loop detector saw cut for exposed wires, cracks, potholes, etc.		x		
b. check alignment for sonic, magnetic, and radar-type detectors; verify call inputs to controller phases		x		
c. check anchorage for pressure detector frame and contact units		x		

(Continued)

*Giblin, J.M., W.H. Kraft, J. Rudden and R. Sands, *Traffic Signal Installation and Maintenance Manual*, Institute of Transportation Engineers, Prentice Hall, New Jersey (1989).

=The preventive maintenance activities presented in this table are only to be considered by an agency when developing their own individual maintenance program. Actual preventive maintenance tasks and corresponding intervals will vary by agency based on local conditions and should be predicated on the equipment manufacturers' recommendations as well as the experience of the maintaining agency.

TABLE C.1 (CONTINUED)

TASK	Recommended Interval: MONTHS 3	6	12	YEARS 2 to 5
Amplifiers				
a. check if the detector is detecting vehicles within its design zone of detection		x		
b. tune the detector if necessary	x			
c. check if the detectors are tight and secure		x		
Junction Boxes and Handholes (per unit)				
a. Check integrity of the splices		x		
b. check the ground rod and clamp connection, and bonding of conduits			x	
c. check the insulation				x
d. check for abnormal amount of water				x
e. check lid for abnormal condition and fit				x
Electromechanical Control Equipment (per unit)				
Dial Assembly				
a. check for wear on key follower			x	
b. check for burned, pitted, or discolored contacts				x
c. check for key positions				x

(Continued)

*Giblin, J.M., W.H. Kraft, J. Rudden and R. Sands, *Traffic Signal Installation and Maintenance Manual*, Institute of Transportation Engineers, Prentice Hall, New Jersey (1989).

=The preventive maintenance activities presented in this table are only to be considered by an agency when developing their own individual maintenance program. Actual preventive maintenance tasks and corresponding intervals will vary by agency based on local conditions and should be predicated on the equipment manufacturers' recommendations as well as the experience of the maintaining agency.

TABLE C.1 (CONTINUED)

TASK	Recommended Interval: MONTHS 3	6	12	YEARS 2 to 5
a. check dial motor operation				x
b. check all dials according to manufacturer's recommendations				x
c. If controller is part of a system, check offset				x
d. check duration of the advance pulse				x
e. clean and lubricate			(as required by manager)	
Cam Assembly				
a. check for end play				x
b. clean and lubricate as required by manufacturer				x
c. visually inspect for abnormal wear or cracks				x
d. check for burned, pitted, or discolored contacts				x
e. check spring tension on contacts			x	
f. check for loose wiring to contacts			x	
g. check for operation of advancing mechanism to conform with manufacturer's requirements				x

(Continued)

*Giblin, J.M., W.H. Kraft, J. Rudden and R. Sands, *Traffic Signal Installation and Maintenance Manual*, Institute of Transportation Engineers, Prentice Hall, New Jersey (1989).

=The preventive maintenance activities presented in this table are only to be considered by an agency when developing their own individual maintenance program. Actual preventive maintenance tasks and corresponding intervals will vary by agency based on local conditions and should be predicated on the equipment manufacturers' recommendations as well as the experience of the maintaining agency.

TABLE C.1 (CONTINUED)

TASK	Recommended Interval MONTHS 3	6	12	YEARS 2 to 5
a. check if all connections are secure and tight				x
b. visually inspect wires for wear, rubbing, deterioration of insulation				x
Relays				
a. check for burned, pitted, or discolored contacts				x
b. check for tight and secure fit into the sockets				x
c. for latch-type relays, check for latch operation per manufacturer's recommendation			x	
Flashers				
a. check flash rate				x
b. check operation				x
c. check for burned, pitted, or discolored contacts				x
d. check for tight and secure fit into the sockets				x
Switches				
a. verify operation of each switch position				x

(Continued)

*Giblin, J.M., W.H. Kraft, J. Rudden and R. Sands, *Traffic Signal Installation and Maintenance Manual*, Institute of Transportation Engineers, Prentice Hall, New Jersey (1989).

=The preventive maintenance activities presented in this table are only to be considered by an agency when developing their own individual maintenance program. Actual preventive maintenance tasks and corresponding intervals will vary by agency based on local conditions and should be predicated on the equipment manufacturers' recommendations as well as the experience of the maintaining agency.

TABLE C.1 (CONTINUED)

TASK	Recommended Interval MONTHS 3	6	12	YEARS 2 to 5
Terminal Connectors				
a. check visually for signs of corrosion or any abnormal condition				x
b. tighten all terminal connections			x	
Solid State, Analog, and Microprocessor-based Control				
Equipment (per unit)				
General				
a. Check if the time settings match the master time sheet			x	
b. check if all indicator lamps on the modules are working, replace failed lamps			x	
c. check for extension by detector actuation				x
d. check if modules are fitting tight and secure into the frame				x
e. check if connectors are tight and secure				x
f. wipe dust off controller, detectors, and auxiliary equipment			x	

(Continued)

*Giblin, J.M., W.H. Kraft, J. Rudden and R. Sands, *Traffic Signal Installation and Maintenance Manual*, Institute of Transportation Engineers, Prentice Hall, New Jersey (1989).

=The preventive maintenance activities presented in this table are only to be considered by an agency when developing their own individual maintenance program. Actual preventive maintenance tasks and corresponding intervals will vary by agency based on local conditions and should be predicated on the equipment manufacturers' recommendations as well as the experience of the maintaining agency.

TABLE C.1 (CONTINUED)

TASK	Recommended Interval MONTHS 3	6	12	YEARS 2 to 5
Conflict Monitor				
a. replace with bench-tested unit			x	
Load Switches				
a. check if load switch packs are fitting tight and secure into their chassis				x
Auxiliary Logic				
a. check operation				x
Relays				
a. check mercury relays (if used) for excessive splash				x
Flashers				
a. check if firm in socket; check on/off ratio and flash rate				x
Switches				
a. check for loose wires				x
Terminal Connections				
a. check for discoloration and tightness				x

(Continued)

*Giblin, J.M., W.H. Kraft, J. Rudden and R. Sands, *Traffic Signal Installation and Maintenance Manual*, Institute of Transportation Engineers, Prentice Hall, New Jersey (1989).

=The preventive maintenance activities presented in this table are only to be considered by an agency when developing their own individual maintenance program. Actual preventive maintenance tasks and corresponding intervals will vary by agency based on local conditions and should be predicated on the equipment manufacturers' recommendations as well as the experience of the maintaining agency.

TABLE C.1 (CONTINUED)

TASK	Recommended Interval MONTHS 3	6	12	YEARS 2 to 5
Interconnected Equipment (per unit)				
a. check if controller operates in the mode selected by the supervisory master (i.e., time-based coordinator)			x	
b. disconnect form the master supervisory system and check for "free" or backup operation			x	
c. check any special equipment per manufacturer's recommendation			As required	
Miscellaneous				
a. record all changes in timing, wiring, or any function			As required	
b. periodically check electric bill for indication of leaky insulation			Monthly	
c. record current flow at unmetered installations			As required	

*Giblin, J.M., W.H. Kraft, J. Rudden and R. Sands, *Traffic Signal Installation and Maintenance Manual*, Institute of Transportation Engineers, Prentice Hall, New Jersey (1989).

=The preventive maintenance activities presented in this table are only to be considered by an agency when developing their own individual maintenance program. Actual preventive maintenance tasks and corresponding intervals will vary by agency based on local conditions and should be predicated on the equipment manufacturers' recommendations as well as the experience of the maintaining agency.

APPENDIX D

Procurement Processes

Procurement is the act of acquiring equipment and services needed to meet the requirements of a particular task. The objective is to obtain the most suitable product for the best price. Several methods of procurement are described in this section. Survey respondents were asked to indicate the procurement processes they use to obtain equipment. Figure D.1 illustrates the percentage of respondents who are responsible for the maintenance of traffic signal control systems in their jurisdiction. As indicated, 83 percent use low-bid, 41 percent use prequalifications, 17 percent use design-build, 12 percent use life-cycle costs, nine percent practice privatization, five percent use facilities management, seven percent indicated the "other" category, and 13 percent did not provide a response.

Low Bid

Low bid is the most often practiced method of procurement by public agencies in the United States. It is the process of choosing products and services based on the lowest bid for the capital costs of the product and services. The process of low-bid purchase is as follows. The purchasing agency (municiplity or other public/private agency) issues nonproprietary specifications for a specific item or for systems. Appropriate "quotes" are then received from interested vendors, distributors, or manufacturers. The agency reviews the submitted lowest bid including item cut-sheets, if appropriate. If the submitted description of the item satisfies the issued specifications, a purchase order is issued by the agency. If for some reason the "offerer" cannot deliver, the award goes to the next lowest bidder or the purchasing authority issues a "rebid."

Facilities Management

Facilities management, also known as systems management, is a procurement method that takes advantage of the bid system while adding a degree of trust and providing the owner with an integrated traffic control system. With this method of procurement, a contractor is employed to develop the software and hardware specifications for the control system. The hardware and construction are then advertised and bid in the conventional manner, ensuring that the client is getting good value by competitive bidding for the vast majority of the project components. The facilities manager also supervises the procurement practices, develops the software, integrates commercial and the applications software with the hardware as it is installed and then provides documentation and training for an integrated system *(1)*.

Life-Cycle Costs

Life-cycle cost procurement is a form of competitive bidding in which a contract is awarded on the basis of a consideration of cost of operation over a designated period of time as well as the initial capital cost *(2)*. It differs from low bid in that low bid is the process of procurement based only on the initial capital costs of a project. Life-cycle cost is normally based on the life of the item with initial capital costs capitalized to reflect annual costs. One of the difficulties with this means of procurement is determining when a device becomes obsolete.

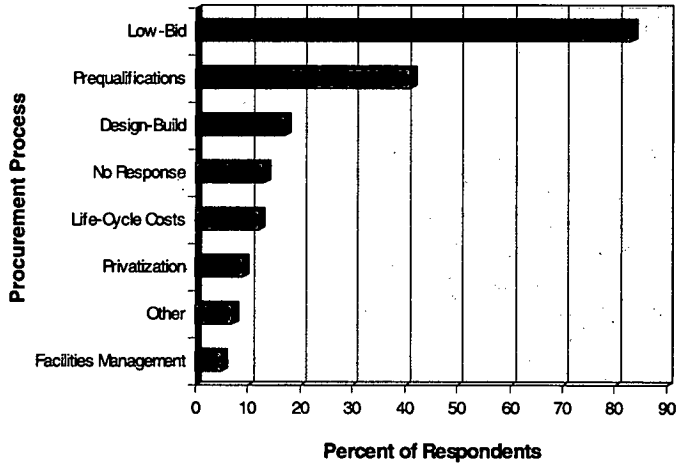

FIGURE D.1 Respondent procurement processes. (Note: Total is greater than 100 percent because some agencies use more than one process.

Prequalifications

Prequalification procurement is most often used when the contracting agency wants to screen equipment, vendors or contractors to assure that each can meet the preliminary specifications. The prequalification type of procurement is a two-step process. The first step is to evaluate the bidders' qualifications and experience to determine if they have the ability to undertake the specified project. The second step is similar to the low-bid process except that the lowest bid does not always assure a purchase order. Qualifications play a major role in the final contract award.

Privatization

Privatization, by definition, is the contracting of public services or selling of public assets to private industry *(3)*. The maintenance requirements are specified and then contracted out to a private firm for performance

Design Build

Design-build procurement is another type of bid process. A contractor is selected based on a bidding process to first design and then implement the project. Staged construction allows the contractor to design an aspect of the project and submit the design for approval before construction begins. At the same time, design of another project component begins. In this way, several stages of the project are performed at the same time and subconsultants can also be employed by the contractor. It is important that these contracts require periodic deliverable products keyed to periodic contract payments so that contract progress can be measured and evaluated.

Acceptance Testing

Acceptance testing is a method of quality control by which the contractor's work is inspected and approved or disapproved based on the contract specifications. If the completed work meets the contractual specifications, then the contractor is eligible for payment. Testing focuses on the final product and whether that product meets the functional or material specifications of the contract *(4)*. Usually an acceptance testing procedure is used by the purchasing agency or its consultant and the supervising engineer oversees the testing process. Each item of the procedure is signed as accepted or rejected by the supplier and the representative of the purchaser.

Maintenance Inventory (Contracting versus Stocking)

There are two main methods for maintenance inventory. One is to contract services for spare parts. The other is to stock a percentage of spare parts for maintenance purposes. Of the individuals surveyed who manage the maintenance activities in their region, five percent contract maintenance inventory whereas 68 percent stock at least some spare parts. Eighteen percent did not indicate a response and eight percent indicated they do not stock or contract for spare parts.

Legal Issues

Survey respondents were asked to indicate the legal issues they believe are associated with procurement. Thirty-six percent did not respond to this question; 22 percent indicated that they believe there are no legal issues associated with procurement. Of the remaining 42 percent, 18 percent cited the laws and issues related to the low-bid process including: the lowest bid is not always the best, laws require the use of low-bid only, agencies are forced to follow good specifications but use the lowest bid, assurance of competitive bids, too much focus on initial costs, and conflicts of interest.

Five percent of the respondents indicated problems with vendors such as accepting gifts from vendors, conflicts with vendors over standards and specifications, collusion with vendors/manufacturers, and vendor complaints. Three percent indicated that the laws requiring the use of minority or women-owned firms is a legal issue associated with procurement. Another three percent cited sole-source, in which there is only one supplier for an item, as a potential problem with procurement. Of the remaining 13 percent, the following legal issues were cited:

- new equipment must be technically accurate but generic in nature
- proprietary issues
- getting bidders on the approved list
- fair bidding practices
- legal relations with respect to public prosecution
- warranty, qualifications and selection
- use of proprietary traffic control
- contract tender procedure.

One respondent indicated that the agency avoids legal issues with respect to procurement by following the state DOT's standards.

APPENDIX E

Appendix References

1. Giblin, J.M., W.H. Kraft, J. Rudden and R. Sands, *Traffic Signal Installation and Maintenance Manual,* Institute of Transportation Engineers, Prentice Hall, New Jersey (1989).
2. Kraft, W., *Intelligent Transportation Systems (ITS): Solutions for the Asia Pacific,* TransAsia Conference, Singapore, China (August 1995).
3. *Glossary of Transportation Terms,* Transportation Research Board, National Research Council, Washington, D.C. (1994).
4. *Traffic Systems Installation, Maintenance and Operations,* ITE (May 1995).

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The National Academy of Engineering was established in 1964, under the charter of the National Academy of Sciences, as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encouraging education and research, and recognizes the superior achievements of engineers. Dr. William A. Wulf is president of the National Academy of Engineering.

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The National Research Council was organized by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and advising the federal government. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. The Council is administered jointly by both Academies and the Institute of Medicine. Dr. Bruce Alberts and Dr. William A. Wulf are chairman and vice chairman, respectively, of the National Research Council.

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