NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
SYNTHESIS OF HIGHWAY PRACTICE **22**

MAINTENANCE MANAGEMENT OF TRAFFIC SIGNAL EQUIPMENT AND SYSTEMS

RESEARCH SPONSORED BY THE AMERICAN ASSOCIATION OF STATE HIGHWAY AND TRANSPORTATION OFFICIALS IN COOPERATION WITH THE FEDERAL HIGHWAY ADMINISTRATION

AREAS OF INTEREST:
MAINTENANCE, GENERAL
TRAFFIC CONTROL AND OPERATIONS

HIGHWAY RESEARCH BOARD
DIVISION OF ENGINEERING NATIONAL RESEARCH COUNCIL
NATIONAL ACADEMY OF SCIENCES—NATIONAL ACADEMY OF ENGINEERING 1974

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway and Transportation Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

The Highway Research Board of the National Academy of Sciences-National Research Council was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as: it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communications and cooperation with federal, state, and local governmental agencies, universities, and industry; its relationship to its parent organization, the National Academy of Sciences, a private, nonprofit institution, is an insurance of objectivity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

The program is developed on the basis of research needs identified by chief administrators of the highway departments and by committees of AASHTO. Each year, specific areas of research needs to be included in the program are proposed to the Academy and the Board by the American Association of State Highway and Transportation Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are responsibilities of the Academy and its Highway Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

NCHRP Synthesis 22

Project 20-5 FY '73
ISBN 0-309-02205-3
L. C. Card No. 74-3531

Price: $4.00

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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PREFACE

There exists a vast storehouse of information relating to nearly every subject of concern to highway administrators and engineers. Much of it resulted from research and much from successful application of the engineering ideas of men faced with problems in their day-to-day work. Because there has been a lack of systematic means for bringing such useful information together and making it available to the entire highway fraternity, the American Association of State Highway and Transportation Officials has, through the mechanism of the National Cooperative Highway Research Program, authorized the Highway Research Board to undertake a continuing project to search out and synthesize the useful knowledge from all possible sources and to prepare documented reports on current practices in the subject areas of concern.

This synthesis series attempts to report on the various practices without in fact making specific recommendations as would be found in handbooks or design manuals. Nonetheless, these documents can serve similar purposes, for each is a compendium of the best knowledge available concerning those measures found to be the most successful in resolving specific problems. The extent to which they are utilized in this fashion will quite logically be tempered by the breadth of the user's knowledge in the particular problem area.

FOREWORD

By Staff
Highway Research Board

This report will be of special interest to state and local maintenance administrators, traffic control and operations officials, and others responsible for managing the maintenance of traffic signal equipment and systems. Current agency practices in executing the various management functions of staffing, equipping, establishing communications, budgeting, operating, and controlling to provide the services of routine maintenance, preventive maintenance, and emergency repair of traffic signal equipment and systems are reported and evaluated.

Administrators, engineers, and researchers are faced continually with many highway problems on which much information already exists either in documented form or in terms of undocumented experience and practice. Unfortunately, this information is often fragmented, scattered, and unevaluated. As a consequence, full information on what has been learned about a problem is frequently not assembled in seeking a solution. Costly research findings may go unused, valuable experience may be overlooked, and due consideration may not be given to recommended practices for solving or alleviating the problem. In an effort to resolve this situation, a continuing NCHRP Project, carried out by the Highway Research Board as the research agency, has the objective of synthesizing and reporting on common highway problems—synthesis being defined as a composition or combination of separate parts or elements so as to form a whole greater than the sum of the separate parts. Reports from this endeavor constitute a special NCHRP Report series that collects and assembles the various forms of information into single concise documents pertaining to specific highway problems or sets of closely related problems. This is the twenty-second report in the series.

Consequences of the breakdown or malfunctioning of traffic signal equipment and systems include important increases in accident potential, and disruptions of traffic flow that are both aggravating and costly to the highway user. The resulting congestion can also be cited as a contributor to air pollution. The frequency of failure, and the time-span of outages, are strongly related to the quality and level of maintenance that is provided. This is also true of equipment life.

This report of the Highway Research Board describes the management measures that are being applied by a variety of agencies representing a wide range of responsibility with respect to the number and complexity of the equipment units and systems for which they have maintenance responsibility. Individual operations that have been used with evident success, including handling of maintenance repairs, routine inspection and maintenance of parts, furnishing and stocking of repair shops, attraction and retention of personnel, and record keeping and documentation, are described and analyzed.

To develop this synthesis in a comprehensive manner and to insure inclusion of significant knowledge, the Board analyzed available information (e.g., current practices, manuals, and research recommendations) assembled from many highway departments and agencies responsible for highway planning, design, construction, and maintenance. A topic advisory panel of experts in the subject area was established to guide the researchers in organizing and evaluating the collected data and for reviewing the final synthesis report.

As a follow up, the Board will attempt to evaluate the effectiveness of this synthesis after it has been in the hands of its users for a period of time. Meanwhile the search for better methods is a continuing activity and should not be diminished. An updating of this document is ultimately intended so as to reflect improvements that may be discovered through research or practice.

CONTENTS

ACKNOWLEDGMENTS

This synthesis was completed by the Highway Research Board under the supervision of Paul E. Irick, Assistant Director for Special Projects. The principal investigators responsible for conduct of the Synthesis were Thomas L. Copas and Herbert A. Pennock, Special Projects Engineers.

Special appreciation is expressed to Gerhart F. King, Consulting Engineer, who, as special consultant to the Topic Advisory Panel, was responsible for the collection of data and preparation of the report.

Valuable assistance in the preparation of this synthesis was provided by the Topic Advisory Panel, consisting of Thomas J. Foody, Traffic Research Engineer, Bureau of Traffic, Ohio Department of Transportation; Stanford P. Gross, Superintendent, Traffic Engineering Operations, Department of Streets and Traffic, City of Detroit; Marshall Jacks, Jr., Chief, Signals and Communications Branch, Traffic Control Systems Division, Office of Traffic Operations, Federal Highway Administration; A. C. Kanz, Deputy Director, Department of Transportation, Montgomery County, Md.; Juri Raus, Highway Research Engineer, Traffic Systems Division, Office of Research, Federal Highway Administration; and Kenneth W. Smith, Director of Traffic, Department of Traffic, City of Alexandria, Va.

K. B. Johns, Engineer of Traffic and Operations, Highway Research Board, assisted the Special Projects staff and the Topic Advisory Panel.

Information on current practice was provided by many states, counties, and cities. Their cooperation and assistance were most helpful.

MAINTENANCE MANAGEMENT OF TRAFFIC SIGNAL EQUIPMENT AND SYSTEMS

SUMMARY

The variety of techniques used by agencies throughout the United States to maintain their traffic signal equipment and systems engenders a variety of both technical and management problems. Although the technical problems obviously are important, the scope of this synthesis is limited to the equally important management problems.

Maintenance of traffic signal equipment and systems falls into several categories. First is the routine maintenance to ensure that the signals continue to operate. This includes lubrication, adjustment, cleaning, and painting. Next is preventive maintenance—the inspection and replacement of parts at regular intervals. Then there are the emergency repairs that are necessary to restore signal operation after a service failure. Signal maintenance may also be done as reconstruction.

Equipment malfunctions (impaired operation without any loss of display) and breakdowns (signal not functioning as a traffic control device) are more likely to occur when there is a lack of routine and preventive maintenance. Other possible effects of lack of maintenance include reduced equipment life, increased accident potential, increased fuel consumption, and environmental pollution.

A maintenance program covers a broad range of work items, Signal heads and poles are visually inspected at frequent intervals—either superficially by driving all approaches to an intersection or, less often, in detail by checking span wire, mast arms, poles, heads, etc.

Relamping procedures vary among jurisdictions. Some replace all burned out lamps as soon as possible; others do this only for red indications and may take a day or two for other lamps. Many agencies have a group relamping procedure. One version is group replacement of red and green indications and replacement of yellow only when failure occurs. Another procedure is to relamp an entire intersection when any indication burns out. Relamping intervals range from six months to two years, with a mean of about twelve months.

Signal lenses and reflectors are cleaned to ensure maximum light transmission. The interval between cleanings depends on mounting height, weather, air pollution, road conditions, etc.; about one year seems to be general practice. Cleaning, relamping, and signal head inspection are frequently done at the same time.

Maintenance of detectors includes inspection to determine if they are operating properly and tuning, if necessary. This is done at one- to three-month intervals.

Control equipment is inspected to verify that it is operating as designed. For signal systems, the route is driven to check progression. Controller timing is usually checked with a stopwatch. Electromechanical equipment requires periodic lubrication and adjustment. Repair of control equipment is usually done at the shop; many shops are equipped to perform complete overhaul of controllers. Some agencies report shop overhauls at intervals ranging from six months to two years. Special problems are associated with central computer control of traffic signal

systems. These include contracting for maintenance and repairs, time-sharing problems, and maintenance and updating of the computer software.

The level of maintenance may be measured by how fast malfunctions and breakdowns are detected and corrected. Detection may be performed through regular patrolling, through employee patrolling while driving to and from work, and through cooperation of police and other government employees. Reports frequently are received from the public, although there are problems in letting the public know where to report. Some central control equipment has built-in self-diagnostic capability.

Once a signal problem has been detected, a repair crew must be dispatched to the site. The procedures used depend on the size of the agency and may be simple verbal instructions or a formal written work order. Some agencies assign work to a crew immediately upon notification; in others the dispatcher holds work assignments until a crew becomes available. During off hours many agencies have a rotating duty roster of personnel to be called for emergency repairs.

Signal maintenance personnel are usually trained by the agency, although they may possess a general background as an electrician or electronic technician. Training may be on the job, through formal courses, or by a manufacturer of signal equipment. Because the maintenance organization must compete with electrical contractors, utility companies, electrical manufacturers, etc., for skilled employees, it may be difficult to retain the trained personnel if the agency cannot pay prevailing wage rates.

Equipment for signal maintenance includes vehicles (standard and specialized types), tools, and test equipment (often custom-made). Spare parts for signal heads, detectors, controllers, etc., are carried at a level that will ensure a high probability of having a replacement when needed.

The signal maintenance function is most often part of a Traffic Bureau or similar unit. Sometimes, however, it may be part of a maintenance unit or an electrical services unit.

A number of jurisdictions have signal maintenance performed under contract. The contractor may be another government organization, such as a city maintaining state-owned signals within the city limits, or it may be a public utility company or electrical contractor.

In addition to responsibility for routine maintenance, preventive maintenance, and emergency repairs, the maintenance organization may also be responsible for traffic signal alterations, construction, and reconstruction, as well as maintenance of other systems such as street lighting, fire alarms, and communications.

Because maintenance of traffic signals involves a major investment in manpower, material, and funds, it requires a high degree of management. Service histories of all signalized intersections, as kept by nearly all agencies, are important because they form the basis for planning, design, and maintenance decisions. They should be as complete as possible to enable easy evaluation of the maintenance history of an intersection or of types of equipment. Management control of inventory is necessary to assure that material, equipment, and supplies will be available when required. Administrative controls include work order completion reports to tell how, when, and by whom the work was done; materials reports to set and keep inventory levels; labor records to assure efficient use of manpower; and equipment records to help schedule maintenance or replacement of equipment.

Fiscal controls include cost accounting, budgeting, and payroll control. These are necessary to keep costs as low as possible and to know how much is being spent and where it is spent. Even with these controls, the cost of maintaining an intersection is difficult to determine. Many costs, such as overhead, are not traceable to a specific intersection or cannot be fairly apportioned.

Some of the conclusions reached are:

- Deficiencies in maintenance lead to signal malfunctions or breakdowns that cause delays to the traveling public, increased accident potential, increased fuel consumption, and air pollution. Thus, it is important to have a signal maintenance program that includes routine and preventive maintenance to ensure that problems are kept to a minimum.
- An important factor in the maintenance management of traffic signal equipment and systems is location of the signal maintenance unit within an organization. The most logical location is within a Bureau of Traffic or equivalent unit.
- "As built" plans and service records are essential to efficient operations of the traffic organization. The "as built" plans make it easier to locate all the component parts of a signal installation, especially underground components. Service records are used to make planning, design, and maintenance decisions and must be accurate, complete, and easily accessible.
- Because of the financial restraints faced by many jurisdictions, requests for appropriations are coming under closer scrutiny. In competing for the necessary funds, signal maintenance officials will face a difficult task unless they can clearly document expenditures and the additional benefits that can accrue from increased appropriations.

CHAPTER ONE

INTRODUCTION

Traffic operations agencies throughout the United States use a variety of techniques in the maintenance of their traffic signal equipment and systems and, consequently, encounter a variety of maintenance problems. Two types of maintenance problems must be distinguished. The first is the technical aspects of maintenance. However, this synthesis concentrates on the second problem, which involves the management aspects of traffic signal maintenance, involving organizational structure, scheduling, resource allocation, financing, and personnel management. Each of these directly affects the quality and level of maintenance.

TYPES OF MAINTENANCE

Routine Maintenance

Routine maintenance consists of those work items that must be done regularly to ensure that traffic signal equipment will continue to operate. The work is caused by the fact that the equipment includes moving parts and intermittent electrical circuits and is exposed to weather and other environmental effects. The major items are lubrication, adjustment, cleaning, and painting.

Preventive Maintenance

Preventive maintenance consists of those work items that should be done, at scheduled intervals, to minimize the probability of failure. It includes inspection and replacement or repair of component parts that are approaching the expiration of their rated service life. One of the largest single items in this category is group relamping. The demarcation line between routine and preventive maintenance is ill defined, and in practice these two types of maintenance are usually performed at the same time.

Emergency Repairs

Emergency repairs include all work required to restore a signal installation, or system, to its original state after a service failure. The term "emergency" is used here to distinguish this type of maintenance, which is unscheduled, from the scheduled types previously discussed. An actual, physical emergency, requiring immediate response, does not have to be involved in order for work items to be classified as emergency maintenance.

Maintenance by Reconstruction

Both preventive maintenance and emergency repairs can be accomplished by a full or partial reconstruction of a signal installation. This type of maintenance is characterized by the fact that work is done on components that normally do not require preventive maintenance and that have not failed. It may be scheduled or unscheduled and is usually the result of functional inadequacy of the installed equipment or the necessity of making physical changes in the installation due to pavement reconstruction or changes in signalization standards.

RESULTS OF MAINTENANCE DEFICIENCIES

Deficiencies in implementing any of the maintenance types, and especially the first three, will lead to a number of effects.

Equipment Malfunction

Lack of either routine or preventive maintenance will greatly increase the probability of equipment malfunction. In this report, equipment malfunction is any event that impairs the operations of a traffic signal, or a system of traffic signals, without losing the display and sequencing of signal indications to all approaching traffic.

By this definition, equipment malfunction includes all instances of timing failure, short of complete controller hangup; loss of supervisory control; intermittent detector failure; and all other instances of traffic signal operation that exhibit timing patterns, phasing, or offsets different from those designed and originally installed.

Because the timing, phasing, and offsets originally set are those that maximize vehicle flow and minimize delays for the particular location, any malfunction must result in less than optimum intersection operation.

Equipment Breakdown

There is no clear demarcation between equipment malfunction and equipment breakdown. For this report, equipment breakdown is defined as any event that causes a loss of indication to any or all phases or approaches. This may be due to controller failure, phase not being called or not being terminated, cable failure, or failure of all indications for a given phase or approach. Total loss of control, through controller failure or loss of power, is included.

Although not part of the foregoing definition, another set of conditions may be considered as equipment breakdown. These include components of the traffic signal installation that present a physical hazard to vehicular or pedestrian traffic. Included are such items as knocked down signal standards, broken glass in the roadway, exposed live electrical wiring, grounding failure, and open manhole or handhole covers. Also included are such conditions as badly leaning signal standards, incipient failure of mast arm or span wire attachments, and open controller cabinet doors.

As previously mentioned, the demarcation line between malfunction and breakdown is difficult to define. A case in point is presented by misalignment of signal heads. In the case of multiple indications, misalignment of any one head is considered a relatively minor malfunction. In the case of single indications (permitted for minor turn phasing) it may be a major malfunction because the motorist's response will be impaired. If the misalignment becomes so severe that no indication can easily be observed for the single-indication approach, or an indication is visible for an approach for which it is not intended, the misalignment must be classified as equipment breakdown. Lamp burnout presents a similar case. If, after a burnout, an indication is still visible for the approach, it is considered malfunction; if no indication is visible it is a case of breakdown. The key word is "visible"—presence alone is not sufficient. Thus, if the only remaining indication is a post-mounted signal located where trucks and buses may block the view, this signal may not be considered as being visible.

The consequences of equipment breakdown are similar to those of equipment malfunction, but far more serious. Loss of all signal indications to one or more approaches or phases will downgrade the location and reduce intersection capacity. In the case of close intersection spacing, degradation of traffic signal operations can lead to spillback. This is the condition where the queue for an approach to a signalized intersection becomes so long as to block free movement of traffic at an upstream intersection.

Reduced Equipment Life

Traffic signal equipment generally has a long service life. Instances of control equipment, posts, and signal heads in continuous use for 30 years or more are frequent. The most common reason for equipment replacement is technical obsolescence.

This long service life, however, is predicated on proper and regular routine and preventive maintenance. As with any other piece of machinery, or any component exposed to extremes of environmental influences, lack of maintenance will grossly shorten service life. There is some evidence to indicate that modern solid-state control equipment has minimum routine maintenance requirements. Even here, regular inspection, especially of thermal and electrical overload protection equipment, and some degree of preventive maintenance are essential to assure full service life.

The reduced service life caused by lack of maintenance will lead to higher expenditures for replacement and repair of equipment. These additional expenditures often will reduce available funds for other programs and activities.

Highway Safety Implications

A number of effects of signal equipment malfunction and breakdown on highway safety can be noted. The most direct effect is the potential for accidents, involving both vehicles and pedestrians. It also has been shown that sub-optimal signal operation will lead to increased congestion and an increased number of vehicular stops, thus increasing accident potential.

Lack of adequate maintenance can lead to physical breakdown of traffic signal installations. Rusted bolts, frayed span wires, or cracked signal hubs may cause pedestals to topple or overhead signals to fall, thereby causing accidents directly or as a result of sudden avoidance maneuvers. Similarly, missing, cracked, or tottering manhole and handhole covers may lead to vehicular or pedestrian accidents.

Environmental Implications

Lack of signal maintenance leads to signal malfunctions or breakdowns that will increase highway congestion, and the number of stops, thus tending to increase fuel consumption, air pollution, and noise. Air pollution from vehicle emissions is most severe in congested traffic situations when automobiles are operating under stop-and-go conditions. Similarly, highway noise (especially that from commercial vehicles) is greater when accelerating and braking.

Legal Implications

There is a legal duty to maintain the lights in a traffic control signal. If an injury or damage occurs because the signals were not maintained, there may be liability. Recent cases have held cities liable and denied their claims of sovereign immunity.

CHAPTER TWO

DESCRIPTION OF THE MAINTENANCE EFFORT

WORK ITEMS

This synthesis concentrates on the managerial and administrative aspects of traffic signal maintenance and does not present a detailed technical discussion or performance specifications for the various work items.

Traffic signal installations are a specialized subset of the set of electrical devices, be they electromechanical, vacuum tube, or solid state; therefore, standard references on electrical construction and maintenance (such as the National Electrical Code (*16*)*) include pertinent material. A good source of technical signal maintenance information is the literature distributed by signal manufacturers.

Several specialized publications dealing with the technical aspects should be in the library of every official engaged in traffic signal maintenance. Principal among these is the "Traffic Signal Manual" (*14*) available from the International Municipal Signal Association. The "Handbook of Traffic Control Devices," an adjunct to the "Manual on Uniform Traffic Control Devices," also includes much valuable technical material. The Institute of Traffic Engineers has prepared standards for traffic signal heads, pedestrian heads, pre-timed controllers, traffic-actuated controllers, and signal lamps. (All but the last are currently being revised.) Several of the larger jurisdictions, which let maintenance contracts for traffic signals, have prepared detailed technical specifications.

The following is an expanded check list to give an indication of the work items included under the heading of signal maintenance and of the specific maintenance requirements of the components of traffic signal installations and systems.

* References throughout this synthesis are to entries in the selected bibliography (App. A).

Signal Heads and Supports

This section covers maintenance requirements for traffic signal and pedestrian heads, signal pedestals, mast arms, poles, pole bases and foundations, and span wire (Fig. 1).

Inspection

Frequent visual inspection of these components is required. Two levels of inspection should be distinguished. The first of these is superficial and can be accomplished by driving all approaches to the intersection. The purpose is to check for proper signal head alignment, plumbness of posts and pedestals, missing visors, cracked or dirty lenses, defective reflectors, lamp burnouts, and similar items. One maintenance contract requires this inspection to be done once a week, or more often at critical locations. However, it need not be scheduled formally if there is a reliable system of inspection by agency employees or by other public forces.

The second type of inspection is more detailed. It is intended to reveal actual or potential failure in such items as anchor bolts, span wire and span wire attachment, mast arm attachments, signal hubs, and other structural components. It also includes checks for missing, misaligned, or loose pull-box covers; spalling or cracking of concrete bases; and condition of painted surfaces. It is desirable to make this inspection quarterly, although this interval may be varied considering the age of the system, the type of materials used, and the maintenance history.

Extra inspections are performed following high winds, rainstorms, floods, ice storms, etc.

Relamping

The most common instance of traffic signal malfunction or breakdown is the burnout of signal lamps. Expeditious replacement of burned out lamps is thus an essential part of a good traffic signal maintenance program.

For continuous safe and efficient operation of the signalized intersection, replacement of all burned out lamps as soon as possible following detection of the outage is the preferred and recommended procedure. However, due to budgetary or manpower limitations, a number of jurisdictions have been forced to depart from this procedure. For example, the burnout replacement procedure may consist of immediate replacement of all failed lamps in red indications or in any indication where only one signal head controls a certain traffic movement (e.g., left-turn signals). One or two working days may elapse before other burned out lamps are replaced.

Some jurisdictions are unable to furnish emergency repair service outside of normal working hours or on weekends and holidays; thus, complete signal shutdown may be required if all red indications are lost for any one approach.

A number of different combinations of these procedures are possible. Thus, different policies may be adopted, depending on the time the burnout report is received. Alternatively, a priority list of critical intersections may be prepared where burnouts will be replaced immediately.

Because replacement of individual burnouts is an expensive process, most jurisdictions are trying to minimize this task by group replacement of all lamps at regularly scheduled intervals. Although blanket group replacement is the rule, several variations thereof can be noted, the most common consisting of group relamping of only red and green indication lamps and replacement of others as failure occurs or at every second scheduled group relamping. Another variation representing a compromise between burnout replacement and group relamping consists of relamping an entire intersection, or the red and green indications only, whenever any burnout occurs at the intersection.

The proper group relamping interval depends on the relative costs per lamp of group relamping and burnout replacement, the expected average service life of the lamps used, the probability distribution of failures, the burnout replacement policies adopted, and policy decisions concerning the mean number of service failures that can be accepted.

Standard mathematical techniques are available to determine the optimum group relamping interval for any combination of these variables and can be found in textbooks on operations research. These procedures are based on the mathematical theory of recurrent events. (For example, see Smith and Oppenlander (*12*).)

Traffic signal lamps are available with a rated service life of 6,000 or 8,000 hr. Information available from lamp manufacturers includes output depreciation curves that show the percentage of rated life in operation, and lamp mortality curves that show the percentage of original lamps remaining after the expiration of various incremental portions of rated lamp life.

Manufacturer's rated lamp life is expressed in terms of burning hours. The number of hours that a lamp is actually burning depends primarily on signal phasing and timing; for actuated installations this can only be determined approximately. In addition to burning time, manufacturing variations and other factors affect the probability of lamp failure. These include frequency of on-off cycles, variations in line voltage, climatic conditions, and vibrations due to heavy commercial traffic. Some jurisdictions, especially those with large numbers of signal installations, may establish and calibrate their own mortality tables in order to be able to initiate an optimum group replacement schedule.

Group replacement intervals ranging from six months to two years are reported. The mean interval appears to be about twelve months. At least one jurisdiction reports a variable group relamping interval triggered by the number of service burnouts reported.

In establishing a group relamping interval, the desired cleaning interval should be considered because the two tasks have many parallel features.

Cleaning

Traffic signal lenses and reflectors, and lamps if not replaced at the same time, must be cleaned regularly to ensure maximum light transmission. A dirty signal lens robs a traffic signal of the required target value, especially if the signal is competing with advertising displays or subject to sun glare.

Because a number of different materials are used for both signal lenses and reflectors, manufacturers' instructions as to cleaning materials and methods should be followed. Washing is recommended, although under certain weather conditions only dry wiping will be possible.

At each cleaning, the integrity of mechanical and electrical connections in the signal head should be checked, as well as proper location of the lamp. The condition and operation of the signal door hinges, latch, and gasketing should be inspected at the same time.

The cleaning interval depends on a variety of local conditions. These include mounting height, weather, air pollution, road and shoulder surface conditions, and type of visors used. A maximum cleaning interval of one year appears to be the general practice, although more frequent cleaning, especially in jurisdictions with a great number of adverse factors, is highly recommended.

It is customary to combine cleaning, relamping, and signal head inspection. This combined operation, which is extremely cost effective, will have a bearing on the scheduling of the three individual operations but should not be used as an excuse to extend the interval between any of these much beyond optimum. Additional cleaning should be scheduled after periods of extremely adverse conditions, such as a severe dust storm.

Repair

Any component part of the traffic signals found to be defective during any inspection, or showing evidence of incipient failure, should be replaced. The most common repairs involve replacement of visors, lenses, reflectors, and sockets. This can be accomplished easily in the field.

Other types of repairs, notably those involving damage to the castings or to other structural components, are best done in the shop. It is customary to replace a damaged signal head or post in the field and to do major repair and reconditioning in the shop. The repaired item is then added to maintenance stock. Because modern traffic signal heads are sectional, it is a fairly easy task to disassemble the signal head when it is brought to the shop, repair salvageable sections and discard those that are not, and then either store individual sections or assemble them into standard configurations.

Repair of posts and pedestals, with minor exceptions such as replacement of pull-box doors, are always done in the shop if they are done at all. Drawn steel poles can be welded; however, this is more difficult with aluminum due to age hardening. New bases can be attached; sometimes it is possible to cut off the damaged section of a pole and reuse it where a shorter pole is required.

Inspection of all poles should be made, even if the pole is not the property of the agency responsible for the traffic signals. Light poles and utility poles are frequently used for the attachment of traffic signal heads or mast arms. A definite procedure should be established for notification and prompt repair of non-owned poles.

Painting

Traffic signal heads and posts are painted for two reasons. The first is for the protection of metal surfaces, except aluminum. The second is for enhancement of the target value of the signal installation.

The paint film deteriorates due to age, atmospheric pollutants, and sunlight, and is damaged by abrasion from airborne particles, accidents, and vandalism. Most jurisdictions repaint signal installations on a fixed time schedule; a few report spot touchup painting between complete repainting. The interval between painting varies among jurisdictions and may not be the same for an entire signal-maintaining jurisdiction, especially if it covers a fairly large or nonuniform geographical area. A difference in location of one mile or less can result in major differences in the amount of paint deterioration due to such factors as salt or atmospheric pollutants.

Painting intervals ranging from two to five years have been reported, with four years as an approximate median.

Cable and Conduit

Multiconductor electric cable is used to connect the traffic signal heads and detectors to the controller, and the controller to a power source. Adjacent intersections, or entire traffic signal systems, may be interconnected by means of multiconductor cable, paired telephone cables (either leased or owned), or radio. Cable can be directly buried, installed in conduit, or installed aerially on poles. Cost will usually determine the method of installation, although aesthetic considerations may take precedence in some jurisdictions.

Inspection

Inspection of underground installations is almost impossible because of their hidden nature. Where underground cable is exposed, such as in handholes or pull boxes, it can be inspected visually. If any malfunction is suspected, appro-

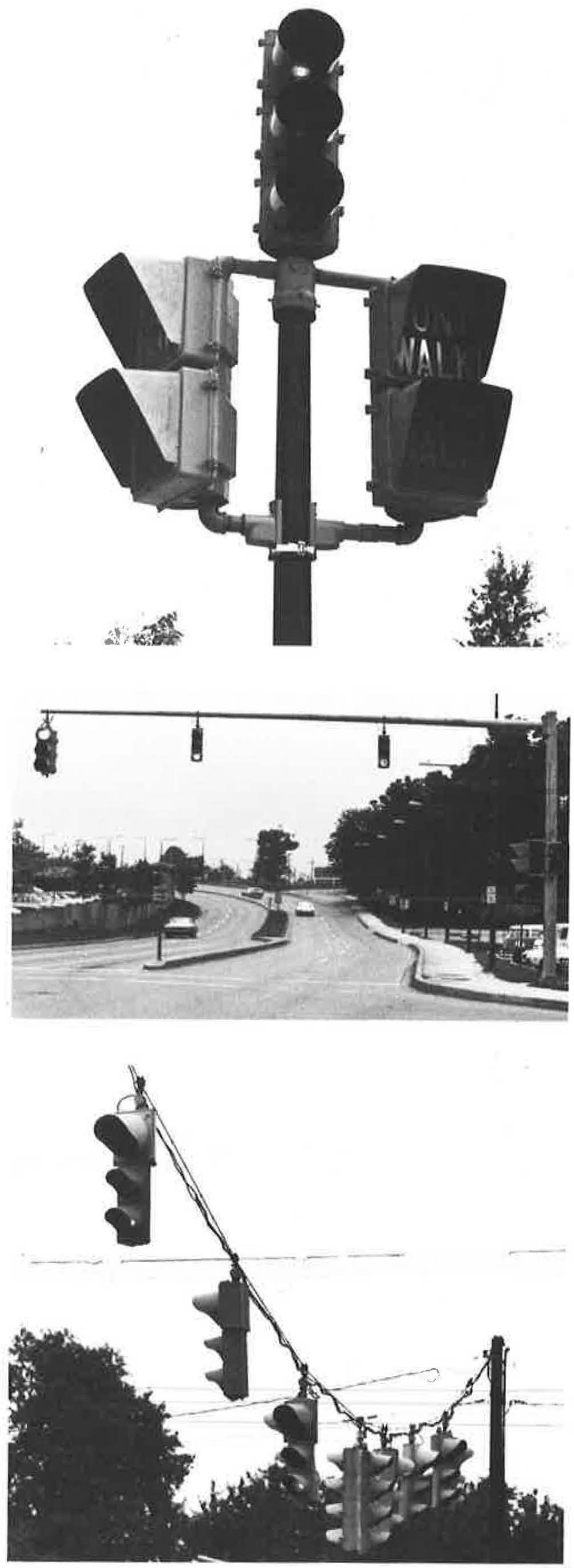

Figure 1. Signal heads and supports.

priate electrical tests, such as resistance to ground, can be made.

Conduit failure is rare if the conduit has been properly installed. No inspection is customarily made except to open handholes to determine if cable can be moved easily in the conduit.

Aerial cable should be inspected, together with messenger wire, if used, and accessories. Inspection can be visual and supplemented by electrical tests if any malfunction is suspected.

Repair

Any cable found to be defective should be repaired or replaced. If only a single conductor is affected, a spare conductor, if available, can be used in replacement. If there are no spare conductors, the entire cable can be replaced or, if there is excess room in a conduit installation, an additional cable may be pulled in. In replacing cable, standard electrical construction procedures should be used.

Detectors

In recent years the number of detector types has greatly multiplied. Detectors in use now include pressure pads, magnetic, inductance loops, ultrasonic, magnetometers, radar, and others (Fig. 2). They may be installed in, under, or flush with the pavement; overhead; or to the side of the roadway.

Inspection

The purpose of most detector inspection is to determine whether the equipment is operating as designed; that is, whether it is detecting vehicles within its design zone of detection. This is usually accomplished by monitoring the detector output, through use of built-in indicator lights or

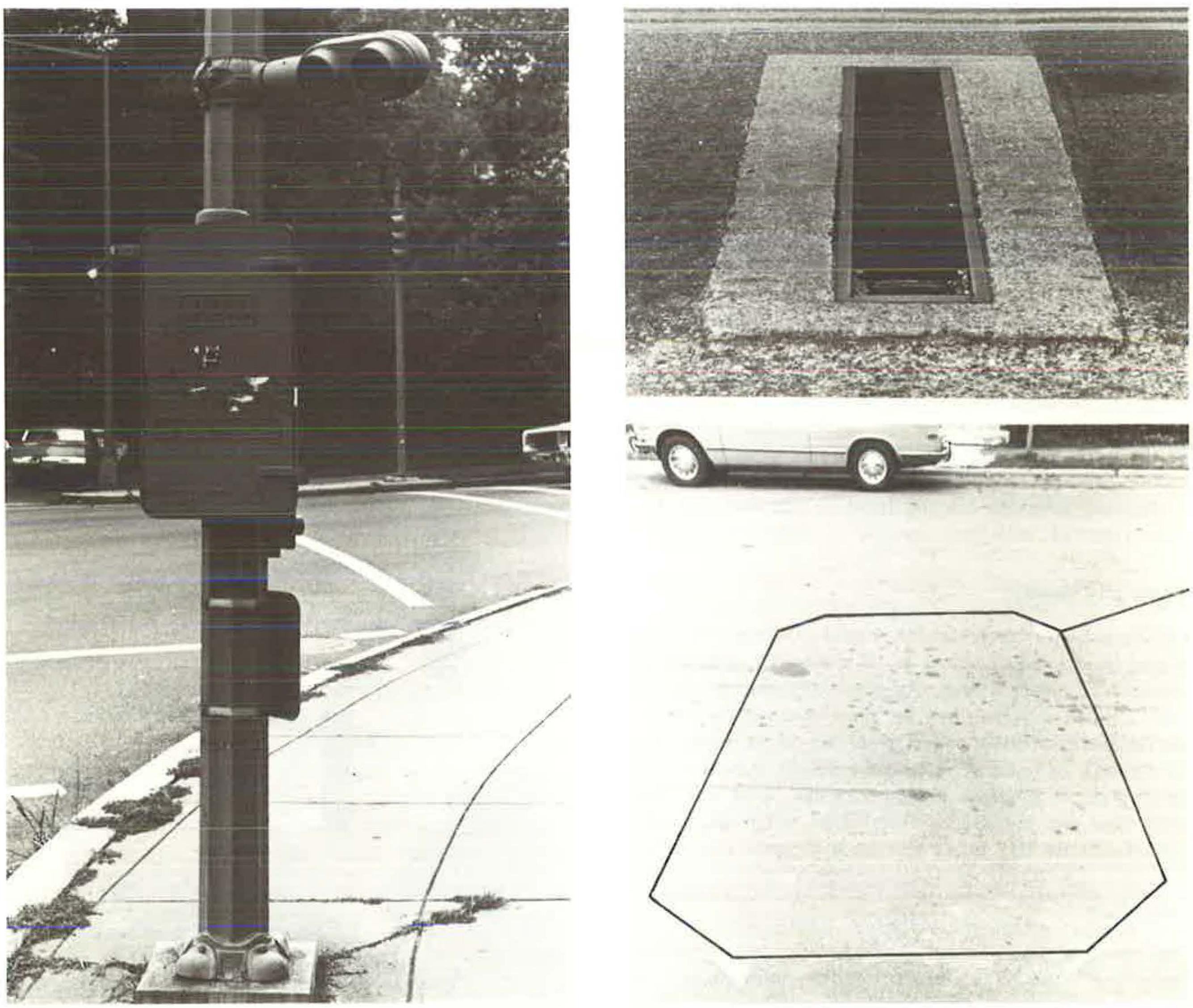

Figure 2. Detectors (left, ultrasonic; upper right, pressure pad; lower right, loop).

by means of a meter, while observing traffic passing the detector location.

Magnetic detectors and magnetometers, buried under the pavement, require no other inspection. The cable connections are inspected as discussed previously and the associated electronics are considered part of the control installation. Pressure pads must be inspected for defects in the casting, contact strip, or pull-box cover.

Inductance loops, except for the associated electronics that are considered part of the control equipment, must be inspected for actual (or potential) failure of the wire loop. These loops can break through external causes, or through creeping of the pavement surface if they are installed in asphalt. Under certain conditions the wire loop may also float up to the surface from the saw cut in which it is installed.

Ultrasonic and radar detectors have electronic equipment associated with them that must be inspected in accordance with the manufacturers' recommendations. These types of detectors operate by means of an aimed beam of ultrasound or electromagnetic emissions. Alignment of the emitter and receiver is critical and must be inspected along with the integrity of the mounting.

Tuning

Tuning means the adjustment of certain electronic circuits to achieve proper operation. Although most detector types on the market today are advertised as self-tuning, a number of older types may require periodic adjustment. Even some of the newer types require adjustment if there is a change in the electromagnetic environment or as components degrade through aging.

Unless the maintenance history of an intersection, or of a certain detector type, indicates shorter intervals, detector tuning should be done at one- to three-month intervals.

Repair

Few detector repairs are made in the field. Usually the entire detection unit is replaced and returned to the shop for repairs. Exceptions include replacement of pressure pad contact elements, replacement of plug-in modules in some detector electronics, and resetting of overload protection equipment. Defective loops must be replaced in accordance with standard construction practices for this type of installation.

Control Equipment

Control equipment includes the intersection timing unit (Fig. 3), the associated detector electronics and external load relays, remote master controllers and system supervisory equipment, and auxiliary equipment at both ends. The last group includes interconnection equipment such as signal coders and decoders, line amplifiers and relays, and radio transmitting and receiving units. Because this equip-

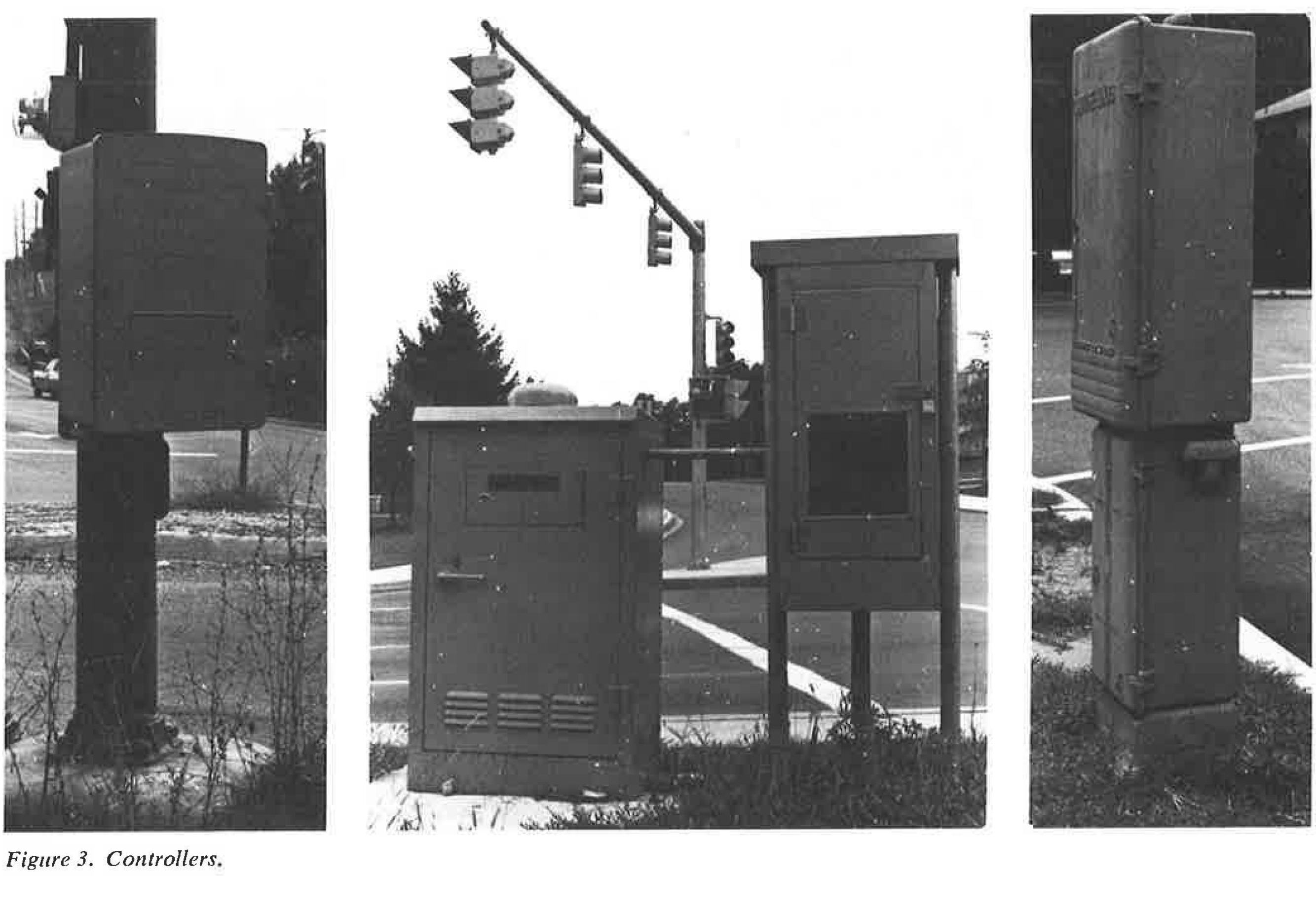

Figure 3. Controllers.

ment includes a gamut of complexity ranging from a simple single-dial, pre-timed electromechanical controller to a major digital computer, few general specifications can be given and only a broad outline of the maintenance task is presented in the following.

Because interconnection lines may not be under the same maintenance jurisdiction as the control equipment, as would be the case with leased telephone lines or the use of spare conductors of a fire alarm system, care must be taken that the agency responsible for these items has adequate maintenance facilities and that close cooperation and communications are maintained between the two agencies.

Inspection

Visual inspection of the intersection operation preferably is done during a period of maximum demand. The observation should extend through several signal cycles. The inspector should notice unequal loading, signal efficiency, and cycle failures for each approach. In the case of signal systems, the route should be driven, in the direction of maximum demand, to check on progression. Although it is desirable to have this kind of inspection done at regular intervals, many agencies do not have a formal schedule. Rather, they rely on the normal driving patterns of their employees and on reports from the police. In traffic signal systems with a self-diagnostic capability, these inspections are less critical and, if scheduled, are usually done more for traffic engineering than for signal maintenance purposes.

A more thorough inspection involves checking on the condition of the controller enclosure, on any heating or ventilating equipment, and on the condition of the wiring harness, terminal-block connections, and fusing. The time interval between inspections of this kind depends on the type and age of the equipment installed. In actual practice it varies widely, ranging from weekly to never. A monthly interval appears to be adequate for control equipment without self-diagnostic capability. More frequent inspections should be scheduled for critical intersections and for intersections that have been reported as malfunctioning intermittently but where no overt cause for the malfunction can be discovered.

Check Operations and Timing

The operation of most types of intersection controllers can be monitored and checked rather closely by visual observation of indicator lamps or by noting the movement of drums, camshafts, or relays. An accurate stopwatch can be employed to check controller timing. The timing of each controller should be checked against its approved timing scheme (a record of which should be kept in the controller cabinet). The timing checked should be the actual timing developed by the machine and not the dial settings. The latter may be quite incorrect, especially in the case of tube-type circuits subject to drifting.

These checks of operations and timing are more difficult in the case of traffic-actuated equipment, especially equipment of the volume-density type that employs the concept of parallel or alternate timing circuits. Because most of these timing aspects are nonlinear with traffic actuations, no simple visual check on timing can be made. In most cases, the only check that can be made is operational; that is, a visual examination of traffic movements, noting such indications of possible faulty operation as unequal queue buildup, excessive slack time, or failure to yield the green to demand on the major artery.

A somewhat different problem is presented by operational and timing checks at intersections that form part of a system. Although offsets, intervals, and phasing can be checked, additional checks are required to determine if the local controller is operating in the mode selected by the system supervisory master. Except for the simplest time-of-day type of operation, this will require obtaining information on the cycle lengths, splits, and offsets currently being generated by the master controller, which may be at a considerable distance. Two-way radio or telephone communications are usually used for that purpose.

All detector electronics installed in the controller enclosure should be monitored for proper operation. The over-all purpose of this task is to ensure that the control equipment is operating as designed and is generating the desired phasing and timing under all conditions of demand. A local controller that receives timing instructions from a master or system supervisory controller should be disconnected from the system to check on proper "free" operations. This does not apply to interconnected signals where the interconnection is for the main purpose of furnishing a background cycle or offsets to assure smooth progression.

Clean, Oil, Adjust

Most modern solid-state equipment is relatively free of routine and preventive maintenance requirements. Electromechanical and vacuum-tube equipment requires lubrication and adjustment.

For all types of control equipment, however, thorough cleaning of the interior of the control enclosure and of the exterior surfaces of the equipment is required. Fan filters should be changed as necessary.

Field maintenance instructions of the control equipment manufacturer should be followed. This will include lubrication of moving mechanical parts, such as camshafts and gears; adjustment of relays; and inspection, and replacement if required, of contact points and indicator lamps.

Repair

Field repair of control equipment, as distinguished from the maintenance work previously described, is seldom done. If repair is needed, the unit is usually removed, an equivalent spare is installed, and repairs are made in the shop. Many types of modern equipment are modular in construction and it is possible to restore a failed unit to proper operation by simple replacement of a plug-in module. Even in older equipment, dial units, external signal relays, and certain other items are replaceable without removing the entire controller.

Shop repair of signal control equipment involves all work required to restore a unit to proper operation. With the more sophisticated modern units, especially those of the multiphase actuated type, troubleshooting is often the biggest and most complex portion of the repair operation.

Although many manufacturers recommend that repair work on the phase module or circuit board level not be attempted by the user and that these units be returned to the factory for repair, a surprising number of jurisdictions, including some relatively small ones, report that they are able to do controller repairs in their own facilities. Each agency must decide for itself which repair policy to adopt and then equip itself in accordance with that decision.

Shop Overhaul

Many agencies report that trouble calls and outages can be drastically reduced by periodic shop overhaul of control equipment. This is especially true of the older electromechanical and vacuum-tube equipment. The maintenance history of newer types of solid-state controllers is not yet extensive enough to make any conclusions or recommendations.

Shop overhaul starts with a complete bench test and disassembly of the equipment. Each part is cleaned thoroughly, tested, and replaced as required. Where experience or manufacturers' recommendations indicate, certain component parts, such as vacuum tubes, other electronic components, or relay springs, may be replaced periodically, even in the absence of overt signs of actual or incipient failure. The overhauled equipment is reassembled and tested again, usually with the aid of specially built test boards that can simulate all possible modes of controller operations.

Agencies that have adopted this kind of preventive maintenance report intervals between successive shop overhauls ranging from six months to two years. The recommended average interval appears to be about twelve months, depending on age and type of equipment and past maintenance history. Some agencies only schedule shop overhaul as a result of repeated failures of a component or in case of intermittent malfunctions that cannot be precisely diagnosed in the field.

Central Control Equipment

Specially built digital computers or standard process computers increasingly are being used as central controllers and system supervisors for traffic signal systems. Each such installation presents its own maintenance problem and no generalized recommendations on maintenance can be made. It is doubtful whether any agency, with the possible exceptions of the three or four largest cities in the nation, would find it cost-effective to do maintenance with their own forces on the central computer and peripheral equipment. Thus, it is customary to award a maintenance contract for this work. Most jurisdictions that have followed this procedure report that the maintenance contract is awarded to the computer manufacturer, to a service subsidiary thereof, or to an independent service firm with close ties to the manufacturer.

Special maintenance problems may be faced by agencies that time-share a large digital computer for traffic control. In this case the computer is used for other city business in addition to its traffic control function. The non-traffic function may represent the largest share of available computing time and the computer may be under the direct control of a different governmental agency. A possible problem arises from the fact that the principal user may be able to operate with a lower maintenance level, in terms of allowable response and down time, than the traffic agency. A "next business day" repair policy may have serious effects on a traffic control system if a computer breakdown occurs at the beginning of a holiday weekend. Jurisdictions intending to follow this procedure should be careful to assure themselves of a proper maintenance level before initiating computer signal control.

Software Maintenance

Digital computer control of traffic signal systems requires a number of computer programs. These programs initiate and control timing, diagnosis, data collection, and other functions of the system. Although the original software package is customarily furnished with the computer equipment, the various programs must be updated and altered as the configuration of the computer controlled system changes, as additional timing routines and data processing routines are tried out, and as different reports on system performance are required.

These procedures, known as software maintenance, are especially important in the first few years of computer signal operations. With two or three exceptions, all existing installations are still in this initial stage. Furthermore, research now being carried out under the auspices of the Federal Highway Administration promises an improvement in the state-of-the-art of signal timing algorithms within the next few years. Use of such an improvement may require reprogramming.

Most jurisdictions require that the original software supplier furnish software maintenance for a given period following initial programming (one year appears to be customary). After the expiration of that period several different procedures are used.

Nearly all jurisdictions have at least one person with sufficient computer programming experience to make minor changes in individual intersection phasing, override instructions, and output format. The training for these individuals is often included in the original installation contract. Programming requirements of a more complex nature may be carried out by agency forces or by consultants. The degree to which a jurisdiction's own forces are used is usually dependent on the size and complexity of the system being controlled and the consequent extent of the programming needs. Competent computer programmers are often available, on a shared-time basis, from other agencies of the government. Before making a decision on this point, however, the traffic agency should carefully examine the qualifications of the available personnel. A programmer, although well versed in scientific or business programs, may not have the real-time programming competence required for the signal control task.

MALFUNCTONS AND BREAKDOWNS

A measure of the level of maintenance is how fast and how well malfunctions and breakdowns are detected and corrected. It is a function of detection, response procedures, corrective measures, and follow-up.

Detection

A number of methods are used, singly or in combination, to detect traffic signal malfunctions.

Patrol

Although regular patrolling of all signalized intersections is desirable, it is not usually done because of budget and manpower limitations. However, critical portions of the signal system may be patrolled daily or even more frequently. These may be expressway control and ramp metering systems, individual arterial systems, or control systems incorporating reversible-lane operations.

Informal, and less than complete, patrolling of signal systems is, however, accomplished by a variety of means. Employees of the traffic agency driving to work, or driving as a result of their other duties, may be requested or required to take certain routes, or to vary the routes they take, and to report any actual or suspected signal malfunction encountered.

The cooperation of the police department may be enlisted. Although police on patrol will generally report all overt instances of signal breakdown, they may not report instances of signal malfunction unless a special effort is made to elicit such reports. This effort must include an explanation of the importance of such reports, an explanation of how to detect common malfunctions and, possibly the most important, an explanation of how malfunction reports are to be worded so as to transmit the maximum amount of correct information. Many jurisdictions have established close working relationships between the traffic and police authorities in this respect. Many furnish written material for distribution to policemen, or for posting in stationhouses. Some traffic agencies are assigned a definite function in the police training program. This includes both recruit training and periodic refresher training. For instance, one jurisdiction reports that a 4-hour session during the formal recruit training program is devoted to traffic signal operations and maintenance, with lecturers and instructional material furnished by the traffic department.

Other public employees, especially those who normally drive publicly owned vehicles equipped with two-way radio, can be enlisted in the patrolling effort on a formal or informal basis.

Public Complaints

Highway users, especially those who drive the same route daily, are usually extremely sensitive to any change in signal control that may be the result of signal malfunction. They represent a potential patrolling force with complete and continuous coverage. However, although many jurisdictions report receiving a substantial number of complaints of malfunctions from the public, little organized effort in this direction has been reported.

To use the public in this inspection and patrolling effort there must be widespread knowledge of three items: what to report, how to report, and where to report. Especially in locations with multiple jurisdictions, such as overlapping city, county, and state signal maintenance responsibility, the last point may become extremely important. Some jurisdictions label the controller cabinet with the name of the owning agency; a few also stencil a telephone number for trouble reporting. Special telephone numbers for reporting may also be listed in local telephone directories.

Efforts to enlist the public include an educational program with the help of the media, lectures in driver training programs, and a widely disseminated, easy reporting procedure. A special effort should be made to obtain the cooperation of fleet operators, especially those whose vehicles are equipped with two-way radio.

Rush-hour aircraft traffic surveillance, operated as a public service by radio stations, often can be a source of indications of traffic signal malfunctions.

Self-Detection

The built-in diagnostic capability of centrally controlled and interconnected traffic signal systems is becoming an important source of malfunction detection for these systems.

These diagnostic features may indicate (via CRT display, hard copy output, or indicator lights) the integrity of the communications circuit, the availability of power at the local intersection, and the status of local timing, as compared to the instructions transmitted by central control. Self-diagnostics can determine whether the local controller is sending the proper commands to the signal heads; they cannot determine whether the appropriate indication is actually being displayed. Self-diagnostics may be able to discover complete detector outages; they cannot, except possibly by inference, recognize intermittent missing of vehicles.

Other indications are available in those systems that employ detectors as traffic sampling devices and where detector impulses are transmitted to central control. With appropriate programming, the computer can make inferential judgments, on the basis of detector information, as to the probability of a signal malfunction.

In most cases, diagnostic messages received from a central computer are inadequate to initiate remedial action and usually must be followed up by a physical inspection of the affected location.

Other Detection Methods

Most agencies use a combination of the foregoing methods for malfunction detection. Although exact records on call origin are not always kept, a number of agencies indicate that either their own forces or the police constitute the biggest source of malfunction and breakdown reports. If contract signal maintenance is used, a portion of the patrolling and malfunction detection burden is assumed by the maintenance contractor. Where frequent patrolling of street lighting is a common practice, this can be combined with a partial patrol of the traffic signal system.

Communications

Reports of signal malfunction or breakdown are received from the agency's own forces, from the police, or from the public.

Reports from an agency's own forces are usually received by radio, telephone, or in person. Larger traffic agencies usually have their own radio system. Smaller agencies may share a radio system with other public agencies. In one agency with limited radio capacity, the traffic forces have been instructed not to report minor signal malfunctions over the air during periods of heavy communications traffic. These reports are deferred for light traffic periods, made via telephone, or made in person when the employee returns to his office.

Reports from the police generally are first received by the police radio dispatcher. They are then transmitted to the traffic department communications center. This may be by regular telephone, dedicated hot-line telephone, or radio. Where the physical location of these two agencies permits, reports may be hand carried.

Reports from the public are usually made by telephone, frequently by letter, and occasionally in person. Because most locations in the United States have multiple governmental jurisdictions (state, county, township, and city) the report may not be received by the proper government. Moreover, the report may be received at any agency within the government and at any office therein.

Calls to City Hall operators concerning state- or county-maintained traffic signals within the municipal limits are a fairly frequent occurrence. The manner of handling these misdirected calls varies between jurisdictions and may vary even within different offices of the same jurisdiction. The employee handling the call may take down the pertinent information and route the report, via internal governmental channels, to the proper office. Alternatively, he may refer the caller to the proper office. Each method has its advantages. If the complaint is handled by the first person reached, the inconvenience to the caller is minimized, thus encouraging further reporting and enhancing the public image of government. On the other hand, the person taking the report is not likely to be acquainted with the technical aspects of signal maintenance, or with aspects of overlapping signal jurisdictions, and may not be able to obtain the maximum amount of pertinent information from the caller. However, he may be able to obtain the caller's name for callback by the appropriate official. If the caller is referred to another number (considering the size of government and the ignorance of its specific functioning on the part of some employees, there may be a number of successive referrals), he is put to a great deal of trouble and may easily give up in disgust. However, if the call can be routed internally to the proper party with little loss of time, these objections can be overcome. Redirecting of calls has the advantage of placing the caller in touch with an individual who can obtain all essential information expeditiously.

To maximize the public as a reporting source, it appears advisable that all government employees in contact with the public, and especially central telephone operators, be trained in the proper method of receiving, recording, and relaying information concerning signal malfunctions. A checklist type of report form (Fig. 4) can be of considerable help in this.

Response Procedure

The response procedure covers dispatching of repair forces in response to a malfunction or breakdown report.

Dispatching

After a report of a malfunction has been received, the traffic communications center transmits the information directly to a maintenance dispatcher or superintendent. These two functions—traffic communications center and maintenance dispatcher—may be combined into one. In most cases, however, the signal maintenance function (shop, garage, warehouse) is physically separate from the traffic department offices. The communications link may consist of regular or hot-line telephone or radio. At least one jurisdiction with contract maintenance has established a teletype link between the main offices of the traffic department and the control center of the contractor.

The maintenance dispatcher or supervisor mobilizes the forces necessary for corrective action. This may be on a verbal or written basis to a work crew present at the shop or by radio to a crew in the field.

If more than one man or crew is available, selection may be based on geographic location, work load, or the type of work to be done. One jurisdiction, which also does its own signal installation work, makes a great effort to have all maintenance and repair work done by the installing personnel.

Repair is usually on a first-come-first-served basis; there may be formal or informal priority schemes, however, depending on the importance of the affected intersection and the severity of the indicated problem. Major signal breakdowns are invariably given priority. For malfunctions the individual repairman or crew is usually given some discretion in scheduling the work. Factors in scheduling include minimizing travel time, expected time to be spent at each location, and known traffic patterns.

The dispatching procedure may be extremely informal if only a few repairmen handle all calls. It may be quite formal for large systems having a number of supervisory levels and crews. The procedure also tends to be more formal if the maintenance function rests with another governmental agency, with a public utility, or with a private maintenance contractor. More than one agency may be involved where specialized equipment (such as cranes) is shared by a number of agencies.

The one exception to this dispatching routine occurs where a malfunction is repaired immediately by a repairman or crew on patrol or en route to another assignment.

DEPARTMENT OF PUBLIC WORKS - TRAFFIC AND PLANNING DIVISION

Traffic Signal Section

Trouble Report

Location ______________________________ Intersection No. ________

Reported by ______________________ Time Call Received __________ Date __________

Maintenance Division ______________ Truck No. __________ Time Technician Notified __________

Time Arrived ______________ Time Completed ______________ Total Travel Time __________

	Red Out	Yellow Out	Green Out	Signal Out	Don't Walk Out	Walk Out	Not Operating	Power Failure	Check Timing	
Trouble Reported										
Trouble Found										

Remarks ____

____

Description of Work Performed __________________________

____

____

____

____

____

Materials Used on this Call

______________ ______________ ______________

______________ ______________ ______________

______________ ______________ ______________

______________ ______________ ______________

______________ ______________ ______________

Revised Timing						
ϕA						
ϕB						

Technician(s) ______________________________ Date __________

Approved by ______________________________ Date __________

Figure 4. Malfunction report.

Time from Breakdown to Repair

The time until repair (that is, the downtime of the traffic signal installation) is an index of maintenance level. This time can be broken into three segments.

Breakdown to Detection.—It is difficult to obtain data on the time between breakdown and detection. The time of breakdown, or beginning of malfunction, cannot be determined unless the equipment has self-diagnostic and recording functions or physical damage is observed when it occurs. In general, detection rapidity is a function of public awareness, patrolling frequency, severity of the malfunction or breakdown, and traffic volumes.

Detection to Dispatch.—Two time intervals are involved between detection and dispatch. The first is the time between detection and notification of the dispatcher. This time may be only a few minutes if the breakdown or malfunction is detected by a highway employee with a radio-equipped vehicle, or by the police. It may be delayed considerably when a citizen makes a report to the wrong government or agency. The second time interval occurs between receipt of the notification by the dispatcher and the actual dispatching action. Frequently a repair crew can be dispatched immediately. However, the dispatching sometimes is delayed, as the dispatcher may be overloaded and not able to attend to the notification report immediately, particularly if several reports are received in a short period of time. Delays also will be encountered if the signal maintenance dispatcher is assigned other duties and, especially, if the other duties are assigned higher priorities. Delays are more probable where a police or fire dispatcher also acts as the maintenance dispatcher. Delays will occur if the dispatcher has no available open radio or telephone channels. Another delay occurs if all available crews are busy or out of communications contact.

Many agencies dispatch immediately upon notification of a breakdown or malfunction. The work is assigned to a crew and the backlog, if any, is theirs. This means that the crew has been dispatched to a number of different locations to do work according to some prearranged priority order. Other agencies keep the backlog with the dispatcher for greater flexibility; the dispatcher sets the priorities and informs maintenance crews of their next assignment only upon completion of the current one.

Various combinations of these dispatch methods are possible. The dispatcher may not begin to hold assignments until each crew has a certain maximum number of uncompleted ones; this number may be fixed or may be a function of expected total time of assignments or time remaining on shift. The dispatcher may assign a minor malfunction to a crew, to be attended to when feasible; a breakdown will be held for priority dispatching of the first crew to complete its current assignment. Or, a priority assignment may be given to a crew to be attended to next, whereas a relatively minor report may be held until some crew, as the result of other assignments, is in the neighborhood of the malfunction.

Adoption of any of these policies depends on the number of available crews, geographical distribution of crews and signal installations, experience and degree of responsibility of the dispatcher and of the work crew, and other factors. However, the specific policy adopted should have little effect on total time to repair. For instance, a policy where the backlog is with the dispatcher will increase the time between notification and dispatch. This, however, will be offset by a corresponding decrease in the interval from dispatch to completion of repairs.

Dispatch to Completion of Repair.—There are three time intervals from dispatch to completion of repair. The first is the time necessary for a crew to assemble or to complete previous assigned work. This time depends on the dispatch policy previously discussed and the total number of crews available.

The second interval is the time necessary for the assigned crew to reach the site. The travel time will depend on local traffic conditions and distance. However, the distance to be traveled depends on the number of crews available, the total area of the maintenance jurisdiction, the geographical crew assignment plan, and location of maintenance yards.

The third interval is the time needed to make repairs. This time will depend primarily on the cause of the malfunction or breakdown and the type of equipment. The rapidity of diagnosis may depend on the kind of routine and preventive maintenance the equipment received. Other factors affecting the speed of repair include the training of the maintenance crew, their equipment, and the spares and parts carried.

Off-Hours Emergency Response

Different methods are used to cover emergency repairs occurring outside of regular working hours. A few agencies keep full operations on a 24-hour basis. These are usually the largest cities or those that employ maintenance contractors. Others reduce their level of operations during off-hours, keeping a minimum number of crews to react to serious breakdowns. Many smaller agencies have maintenance personnel on a rotating duty roster to be called at home for emergency repairs. These agencies may keep a traffic maintenance dispatcher on 24-hour duty. However, a more common practice is to transfer these dispatching duties during off-hours to a police dispatcher, who calls the designated repair crew or duty foreman. A few jurisdictions have no planned response procedure for off-duty hours or for parts thereof (such as from midnight to 6:00 AM). In those jurisdictions, police are usually instructed in signal shut-down procedures and are provided with STOP signs for use where signals cannot be put on a flashing basis. Emergency repairs that cannot be delayed (such as signal knockdowns) are handled on an ad hoc basis.

The decision as to which procedure is to be followed is usually made on the administrative level, with cost considerations playing a major role. Civil service and union rules, and overtime pay practices, are factors in evaluating the costs. For instance, some contracts require pay for a minimum number of hours (as high as three or four hours) for every call-out after normal working hours, irrespective of the time actually taken. Abuses of overtime premium pay have been reported, including unnecessary extension of after-hour repair work and deliberate delaying of regular shift work until the overtime period.

The ideal maintenance program would consist of full 24-hour service. This procedure results in maximum utilization of maintenance equipment and minimum inconvenience, delay, and hazard to the motoring public. It has the added advantage that certain maintenance and repair operations, especially those requiring temporary signal shutdown or occupation of the traveled way, can be accomplished more conveniently and rapidly during lightly traveled nighttime hours. This procedure is, admittedly, more costly and may not be economically feasible in those jurisdictions with a relatively small number of signals.

Corrective Measures

Several measures can be taken to correct malfunctions or breakdowns. The measure used is that which is appropriate for the type of trouble encountered.

Repair

Repair involves performing all work necessary to completely correct the malfunction or breakdown. In nearly every case it is the preferred procedure.

Obviously, complete repairs cannot be accomplished in all instances. For example, proper spares, parts, or equipment may not be available, or physical damage may require replacement of concrete or other work that cannot be done immediately. In these cases the signal operation may be downgraded, changed to flashing, or shut off.

Downgrading

Downgrading includes all those repairs in which a traffic signal installation is made operative, but in a manner different from the design operation. In nearly every case this means a loss in phasing, timing, or offset flexibility; loss of one of multiple indications; or recall instead of actuation for one or more phases.

Downgrading, in many cases, is the result of installing spare control equipment while repair work is performed on the controller. This spare equipment may not have all the features of that originally installed. Downgrading can also be the result of detector failure, with the control set to recall for the applicable phases. Other examples include loss of a protected turn phase, of pedestrian indications, or of interconnection circuits.

An intersection may have to be downgraded because appropriate spare equipment is not available or because the repair crew is unable to repair the defective equipment in the field. This depends on the skill and experience of the crew, the type of equipment and spare components carried, and the sophistication and maintainability of the control equipment.

The decision to downgrade or to repair a signal installation depends on the maintenance policy followed. For instance, some jurisdictions instruct their emergency repair crews to spend as little time as possible at any one location. The minimum amount of work necessary to restore some kind of signal control is done, and permanent repair work is left to a follow-up visit by a regular maintenance or construction crew. This frees emergency repair crews for other calls in the shortest time possible; however, the intersection operates under less than optimum control for a longer period of time. Other jurisdictions follow this "minimum work" procedure only for calls made outside of normal working hours, during relatively heavy traffic conditions, during periods of adverse weather, or under some other predefined set of conditions. Others try to minimize downgrading by requiring that the responding crew spend as much time as necessary at the location and, if possible, repair the signal installation without a follow-up visit.

Flashing Operations

An intersection with defective control equipment can be placed on flashing operations if power is available and indications for all approaches remain operative. This procedure allows work to be done on the control equipment and other portions of the signal installation while retaining a more effective degree of control than that afforded by STOP signs.

Flashing operation is usually actuated by means of a flasher permanently installed in the controller cabinet and wired to give the proper indications. This is the recommended procedure, although flasher units can be carried by the maintenance crew and installed upon arrival. When flashers are permanently installed, the control switch to shift operations to flashing is usually installed in a separate panel accessible to the police. Flashing signal operation can be supplemented by police control during periods of heavy traffic.

Signal Shutdown

Signals must be turned off if work on the controller is necessary and external flashing capability is not provided, or if the work to be done would be hazardous because of live electrical circuits. Selective shutdown should be avoided and at no time should all indications to one approach be turned off while other approaches remain under signal control. However, it is possible to disconnect individual signal heads, if multiple indications are provided, or individual detectors, if the controller has a recall capability.

If signals are turned off completely, for however short a time period, alternate traffic control methods must be employed. These fall into two general classes: police or flagman control, or control with STOP signs. The type of control depends on the time of day, the traffic flow, and the expected duration of the signal shutdown.

Flagman control is rare and is used only for very short intervals while the maintenance crew is occupying the site. At busy intersections traffic control is usually left to trained members of the police department.

Police traffic control is often initiated well before the arrival of the maintenance crew. This is especially the case if the outage is first detected by the police or first reported to the police. In those cases, police control will usually continue until the signals are made operative again. For long outages, the police traffic control may be replaced by STOP-sign control.

The decision on whether police or STOP-sign control should be used in cases of signal shutdown, or whether the STOP-sign control should be two-way or four-way, is critical to the flow of traffic. This decision is made by responsible officials of the traffic department who can take all pertinent factors into account. In case of extended shutdown, STOP-sign control may be supplemented by police control during peak traffic or school crossing periods. Traffic engineering considerations may indicate the need for advance warning signs or the retiming of adjacent intersections to minimize the effect of an extensive shutdown. Many jurisdictions have established contingency plans that indicate clearly, for every signalized intersection in the system, the type of alternate control to be used as a function of time of occurrence and expected duration of the outage.

Follow-Up Procedures

Follow-up includes all work scheduled at locations where emergency repairs did not completely restore service. Maintenance work will only be considered as follow-up if it does not occur in the same shift as the emergency repairs or if it is done by a different maintenance crew. Follow-up work can be scheduled, the resources necessary to complete the work are known, there is a good indication of how long the work will take, and the time pressure to commence and complete the work may be somewhat decreased.

Scheduling of follow-up may include formal work order issuance by a foreman or superintendent or an informal knowledge on the part of a specific crew that they must return to a given location as soon as possible. Where maintenance is done under contract, a work order to a maintenance contractor may be required or a special contract may be awarded.

Work orders for follow-up work should be reviewed by the responsible official to determine if other work can be done at the same time (e.g., upgrading, alteration, normal maintenance).

A few jurisdictions have a policy to keep the same piece of control equipment at the same location. In those jurisdictions a complete repair using substitute equipment will require a follow-up, as the original equipment must be returned to the site after shop repair has been completed. Such exchanges are usually scheduled on an opportunity basis whose urgency depends on the total number of available spare units of a given type. Most jurisdictions, however, do not follow this policy.

After completion of permanent repairs, additional patrolling and inspections may be required to ensure proper operation. Adjustments may also have to be made to inspection schedules, especially if those schedules are developed as a function of equipment age.

RESOURCES REQUIRED

The type and quantity of manpower, equipment, supplies, and parts required will depend on a number of local factors. The following discussion gives a general appreciation of these factors and lists those considerations common to all jurisdictions.

Manpower

By far the most important resource is the manpower devoted to the maintenance effort.

Skills and Number

Several different skills are needed for accomplishment of the maintenance effort. Although job titles and job descriptions vary from one jurisdiction to another, the distinctive skills required are implicit in the description of the maintenance effort. Examples of formal job descriptions are included in Appendix B. Agencies with a considerable amount of solid-state equipment may want to place additional emphasis on experience with solid-state technology.

The basic maintenance tasks are site inspection; repair and installation of signal equipment; and bench repair of electromechanical, vacuum-tube, and solid-state electronic equipment. Thus, the primary skills required are electrician, lineman, and electronic technician (Fig. 5), supplemented by other skills as required. In some areas, individual members of the maintenance crew may possess more than one of these skills. Some skills, such as operators of specialized equipment, can be borrowed from other agencies.

Administrative and clerical workers may be a part of the maintenance organization or they may be shared with other sections of the agency.

The number of personnel assigned to traffic signal maintenance depends on the number of installations maintained, the installation density, the type and age distribution of the

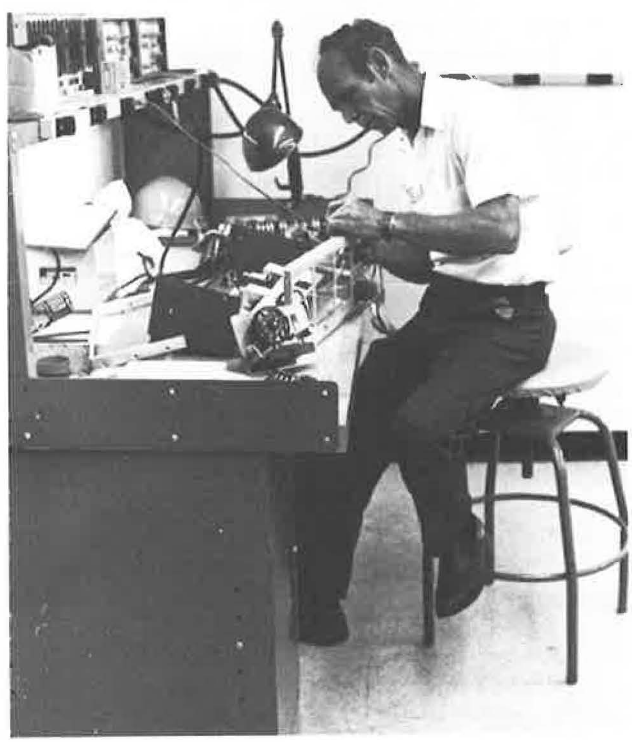

Figure 5. Signal technician.

signal installations, and the level of maintenance. No correlation between the number of installations and the number of personnel could be determined. Ratios from one man for every ten installations to one man for almost one hundred have been noted. Many jurisdictions were unable to indicate the number of man-years used annually for traffic signal maintenance because their maintenance personnel were also engaged in new construction and reconstruction or in maintenance other than traffic signals.

Training

Signal maintenance personnel require the skills specifically applicable to traffic signal installation and maintenance, as well as the skills of their particular trade. Because traffic signal installation and maintenance is almost exclusively a governmental function, no extensive pool of the necessary skills exists in private industry. Although there is some hiring of trained personnel from other agencies, most of those engaged in traffic signal maintenance receive their training within the maintenance organization.

The amount of training received depends on the entrance requirements and hiring policies. Thus, some jurisdictions will hire only experienced electricians or electronic technicians. Industry and the armed forces are the primary sources. At least one jurisdiction requires some formal technical training beyond the high school level, but not actual experience. Another jurisdiction has no entrance requirements other than high school graduation, but has instituted a formal apprenticeship program, including both academic and practical training.

Informal training consists substantially of learning on the job from more experienced personnel. This may be supplemented by financial assistance and/or time off for attendance at technical training courses.

Formal training of signal maintenance personnel can take many forms. It can range from short lectures by experienced personnel within the department to extensive schooling. Training in signal maintenance is available from a number of sources. The courses may be devoted solely to signal maintenance or may include signal maintenance in a program designed to train traffic signal technicians.

Training may be organized by schools and universities either as short courses or as part of a regular curriculum that may even lead to a degree. Training courses also may be offered by unions or by local sections of technical organizations, notably the International Municipal Signal Association. In some instances, state highway departments have organized and conducted formal signal maintenance training sessions for employees of municipalities and counties within the state, as well as for the state's own forces.

Another source of formal maintenance training is the various manufacturers of traffic signal equipment. Although most of the major suppliers claim to provide such instructions, actual practices vary widely. For instance, one manufacturer has regularly scheduled courses of about a week duration at his facilities. Three separate courses are offered covering three distinct classes of signal control equipment. The manufacturer bears all costs of the training, including living expenses, but not transportation.

Another manufacturer has irregularly scheduled, regional training sessions covering maintenance aspects of his equipment. A third conducts training sessions at the customer's facility when requested to do so and if a minimum attendance is guaranteed. Manufacturers are also a prime source of signal maintenance literature for use in training courses. Because the practices of the various manufacturers in this regard change fairly frequently and may differ from one region of the country to another or among various customers, interested traffic maintenance officials should obtain current information directly from specific suppliers.

Several signal maintenance agencies have been able to convince local technical colleges and trade schools to schedule courses and have assisted these institutions in developing course material. State highway departments have also been successful, in some instances, in having state universities develop and offer short courses (e.g., Georgia Institute of Technology). Signal maintenance officials should be aware of the training opportunities available in their geographical areas and should encourage their personnel, as much as possible, to take advantage of these.

Overtime and Standby Procedures

Overtime procedures involve compensatory time, straight pay, or premium pay. These procedures depend on local laws and regulations, civil service rules, and union contracts. Some jurisdictions can require overtime work, others may only request.

Procedures on staffing multi-shift operations vary. One jurisdiction has a normal complement for the first shift, half that number for the second shift, and a skeleton crew for the third shift. Other jurisdictions keep two shifts manned fully and rely on standby arrangements for the third shift; some have complex duty rosters for rotating personnel among the various shifts.

Formal standby procedures to be used outside of regular working hours can take a number of forms. The standby crew may be the only maintenance force available; it may be called only if the amount of work required is too much for the skeleton crew on duty. In one jurisdiction, every regular maintenance man is assigned responsibility for a number of installations near his home. In another jurisdiction, a foreman is on call and is responsible for making the necessary arrangements for the required repair work. In still another jurisdiction, the dispatcher calls names from a priority call list, which is changed at regular intervals. Different procedures may be followed at different times (such as before or after midnight) or they may differ between weekday nights and weekends.

Whichever procedure is used, the personnel must be fully aware of what is expected and under what conditions they may be called. Furthermore, the dispatcher must know exactly whom to call under which conditions and what steps to take if the primary respondent cannot be reached. Because it is desirable for the person on standby to proceed directly to the location of the outage when called, it will be necessary for him to have tools, equipment, parts, and spares on hand or readily available.

The possibility always exists that some natural or man-made disaster or some particular combination of circumstances will overtax all facilities of the maintenance organization. Standby procedures for this possibility have not received sufficient attention in most signal maintenance organizations. These procedures would not depend on the use of skilled personnel borrowed from other agencies (because it is likely that the circumstances will also affect the normal functions of those other agencies) but may include standby arrangements with local contractors.

License and Union Requirements

Some jurisdictions require all maintenance men to be licensed as journeymen electricians; others require this only of foremen or of some senior personnel. Licensing may be a hiring requirement or a promotion prerequisite. Local practices and applicable state laws will play a major role in the decision as to the procedure used.

Some types of control, detection, and interconnection equipment require that personnel directly involved with operation and maintenance hold appropriate FCC licenses. It is the policy of some jurisdictions to reimburse their personnel for the cost of obtaining and renewing these licenses, including, in some cases, the costs of the necessary training. Agencies engaged in traffic signal maintenance would be well advised to procure copies of all pertinent FCC regulations and to keep these up to date.

Some jurisdictions have unions, others do not. These may be electrical craft unions, general industrial unions, or unions of public employees. In those jurisdictions that have unions, responsible officials of the traffic signal maintenance agency must make sure that the union contract reflects the particular requirements of the signal maintenance function. Some jurisdictions report that their operations have been hampered or made unduly costly by requirements of city-wide union contracts that did not account for signal maintenance requirements.

Foremen, Supervisors, Technicians

The need for supervisory personnel depends on the size of the signal system to be maintained, the level of maintenance involved, other functions assigned to the signal maintenance forces, and other factors.

In most jurisdictions, one person is in charge of signal maintenance. A number of intermediate levels of supervision may be provided, depending on the size and complexity of the system to be maintained. These intermediate supervisors may be in charge of defined geographical areas or functional units. Thus, one may be in charge of emergency crews, another in charge of follow-up work, a third in charge of central shop and warehouse facilities, and so on.

The actual maintenance work is under the direct control of a foreman, although there is some supervision by journeymen over apprentices, aides, or laborers. Foremen assist with the work, depending on local practices, union contracts, and crew sizes.

In most jurisdictions, foremen are promoted from the ranks of signal maintenance workers. The same may apply to other supervisory levels, although the higher levels, especially in the larger jurisdictions, are usually filled by engineers.

Two types of technicians are involved in traffic signal maintenance work. The first are highly skilled persons capable of working on complex electronic equipment, individual components, and circuit boards. These technicians usually have one to two years of formal trade school or technical college training. Military veterans with experience and training in electronics and radar have been a major source of technicians.

The second type of technician is the one capable of performing such items as timing, inspection, and patrolling of installations to ensure functional adequacy. Field evaluation of new equipment may also fall into this classification. Persons engaged in these activities usually have some formal traffic engineering and general technical training. However, it is not unusual for signal maintenance workers, through experience and on-the-job training, to acquire the necessary skills to be promoted into this technician classification.

Personnel Recruitment and Retention

Recruitment of signal maintenance personnel follows the prevailing practices for other local public employment. Thus, there may be open hiring and firing, or a civil service system with or without competitive examinations. A hiring system using a recognized labor union hiring hall may be used.

Few jurisdictions reported any difficulty in filling authorized and budgeted positions. Exceptions to this occurred in positions requiring a high degree of skill, such as solid-state repair technician. However, this generally favorable picture is distorted by the serious financial crisis that prevents most public agencies from expanding their signal maintenance forces, even when such expansion is needed by an increase in signal system size, complexity, or age. These budget pressures have led to total or partial hiring freezes that prevent vacancies from being filled.

If a maintenance organization cannot pay prevailing wage rates it will be unable to compete in the labor market. Unrealistic salary schedules are caused by failure to appreciate fully the types of skills required for proper maintenance of sophisticated traffic signal systems and the consequent necessity to pay higher than normal maintenance or electrician rates. Maintenance organizations compete with electrical contractors, utility companies, and electrical and electronic manufacturers. In some areas with large industrial plants or considerable construction activity, certain skills may be completely unavailable.

Signal maintenance organizations sometimes compete with each other, especially in areas where maintenance jurisdictions overlap. This may occur because of different pay scales between governments. Many state highway agencies have statewide wage scales for their signal maintenance personnel. One agency found that the statewide rates were satisfactory and competitive in the rural areas, but encountered problems in retaining trained personnel in the larger urban areas where municipal governments had a higher pay scale.

Maintenance jurisdictions that follow a policy of training their own personnel, rather than hiring experienced employees, may encounter some difficulty in retaining these employees once their training is complete. In extreme cases, these organizations may act as nothing more than a training ground for other users of the same skills. A training program of this kind can be self-defeating unless it is coupled with a salary scale, working conditions, and fringe benefits sufficiently attractive to retain the trained personnel.

Use of temporary employees is not common in traffic signal maintenance work. The few instances of temporary personnel reported were mostly for such purposes as supplementary inspections, inventory, signal painting, etc.

Field Equipment

The type and quantity of field equipment required depends on the characteristics of the system to be maintained.

Automotive Equipment

Automotive equipment is required for patrolling and for transporting maintenance crews and equipment to the job site. In some jurisdictions, employees use their private vehicles on a mileage reimbursement basis; however, the use of publicly owned vehicles is more common. Vehicles are usually assigned to individuals, but some agencies use a central motor pool. Types of vehicles include passenger cars, pickup trucks, vans, and other trucks with special utility bodies.

Specialized vehicles include heavier trucks, often equipped with power tailgates, used for transporting heavy equipment and parts to the job location. These are often equipped with special racks designed to carry long mast arms and mast arm poles. Every jurisdiction has special equipment to enable the work crew to safely reach high-mounted signal heads. These may include platform trucks, cherry pickers (Fig. 6), or truck-mounted aerial ladders.

Other equipment that is usually available to the maintenance organization includes air compressors, concrete saws, and possibly cranes and concrete mixers. For each type of equipment required, a decision is made to buy, share, or rent it. Standard procedures are available to make this determination on a least-cost basis. It is important to include a factor for the varying times required to mobilize the equipment.

Tools

Small hand-tools may be furnished by either the maintenance organization or the individual employee. Larger tools, such as portable power-tools, and special alignment tools for the control equipment, are almost always furnished by the maintenance organization.

When tools are furnished by the maintenance organization some type of control is required to prevent abuses. One jurisdiction has adopted a policy of making an initial distribution of tools to each employee. Tools failing or wearing out in service are replaced. However, tools lost due to negligence on the part of the employee must be replaced by him. If a control scheme is not used, the purchase of small replacement tools can become a major expense.

Figure 6. Cherry picker for signal maintenance.

Test Equipment

Test equipment used includes both standard electrical test equipment (such as voltmeters) and specialized equipment, often custom-made, designed to check specific controller and detector functions. Test equipment is usually furnished by the maintenance organization, although it is not unusual for experienced electricians to use their own.

Miscellaneous

Hard hats and high-visibility vests are furnished by the maintenance organization and are required whenever work is done in and near the roadway. Foul-weather gear and special shoes may be furnished by the organization, or may be furnished by the individual employee with or without a financial allowance by the employer.

A number of jurisdictions issue uniforms or standard work clothes, with organization identification, to all their employees. In most cases, these are rented from an industrial uniform service that furnishes clean replacements at stated intervals. Many jurisdictions, from a public relations point of view, require neat, uniform work clothes for employees that are in contact with the public.

Because field maintenance personnel may be required to enter upon private property or deal with utility companies, the police, or other public agencies, they should be provided with official identification and required to carry this with them at all times when on duty.

All maintenance crews should be trained in the proper use of portable barricades, cones, flashers, and appropriate warning signs required for protection of the work site.

Signal Repair Shop

Major reconditioning, overhaul, repair, and bench testing of traffic signal equipment are done at a signal repair shop (Fig. 7).

Number and Location

Only the largest jurisdictions have more than one signal shop, because of the relatively large investment required for equipment. It is possible to have the shop work split between two locations on a functional basis, such as electromechanical and solid state, but this is rare.

Ideally, the signal repair shop should be located to minimize travel time from all points of the system, especially because the shop is usually combined with the parts and spares warehouse. In practice, however, only a few jurisdictions have signal systems large enough to warrant a separate building and the signal shop is usually located in any available publicly owned building. In many jurisdictions it is combined with the sign shop.

Adequate space, power, and ventilation, and ease of access for truck loading and unloading, are necessary. The shop usually serves as headquarters for the maintenance crews and thus should have such facilities as personal lockers and washrooms. Offices may be provided for supervisory personnel.

Tools

The tools required in a signal repair shop are the basic hand-tools, as well as certain special alignment tools and wrenches required for working on specific pieces of signal equipment. If damaged signal heads and posts are reconditioned, pipefitters' tools, spray-painting equipment, and metal cutting and welding equipment are required. Most shop tools and equipment are furnished by the agency.

Test Equipment

Test equipment for traffic signal work consists of such standard items as VTVMs, oscilloscopes, and substitution boxes, and custom-made equipment for signal testing. It is customary for the signal shop to contain a number of work stations. At each station, test panels and meters are installed to test and troubleshoot a specific type, or family of types, of control equipment. Test boards may be purchased or they may be made by the shop personnel. The number of stations required for each type of equipment depends on the number in operation, the shop overhaul frequency, the expected breakdown rate, the average time spent on each overhaul or breakdown repair, and the utilization (number of shifts) of each station. If acceptance testing of new equipment is also done at the same location, this must be taken into account when determining the number of stations needed.

Some larger jurisdictions have recording meters, environmental test facilities, and other specialized equipment to perform elaborate tests on new equipment. Special equipment is required to repair, adjust, and calibrate items subject to FCC regulations.

Storage Requirements

Storage facilities at the shop are required for tools, equipment, parts, supplies, and equipment awaiting repair (Fig. 8). In conjunction with the signal shop, most jurisdictions operate warehousing facilities where additional parts, equipment, and supplies are stored.

Several agencies, with large geographical areas to cover, have established a system of smaller satellite warehouses where a stock of items in frequent demand is kept available for the maintenance forces. In those cases, the main warehouse acts as a central depository and receiving point, with the responsibility of keeping the smaller facilities stocked. Incoming material inspection is done at the central facility.

The size of the storage facilities depends on the normal inventory level for each item and the prevailing reorder policies. The storage facilities should be arranged on a functional basis and good inventory and security procedures should be followed.

Because some stored items may be required at any time, 24-hour access is essential. Although the frequency of emergency withdrawals can be minimized by adequate stocking of maintenance trucks, they can never be completely eliminated.

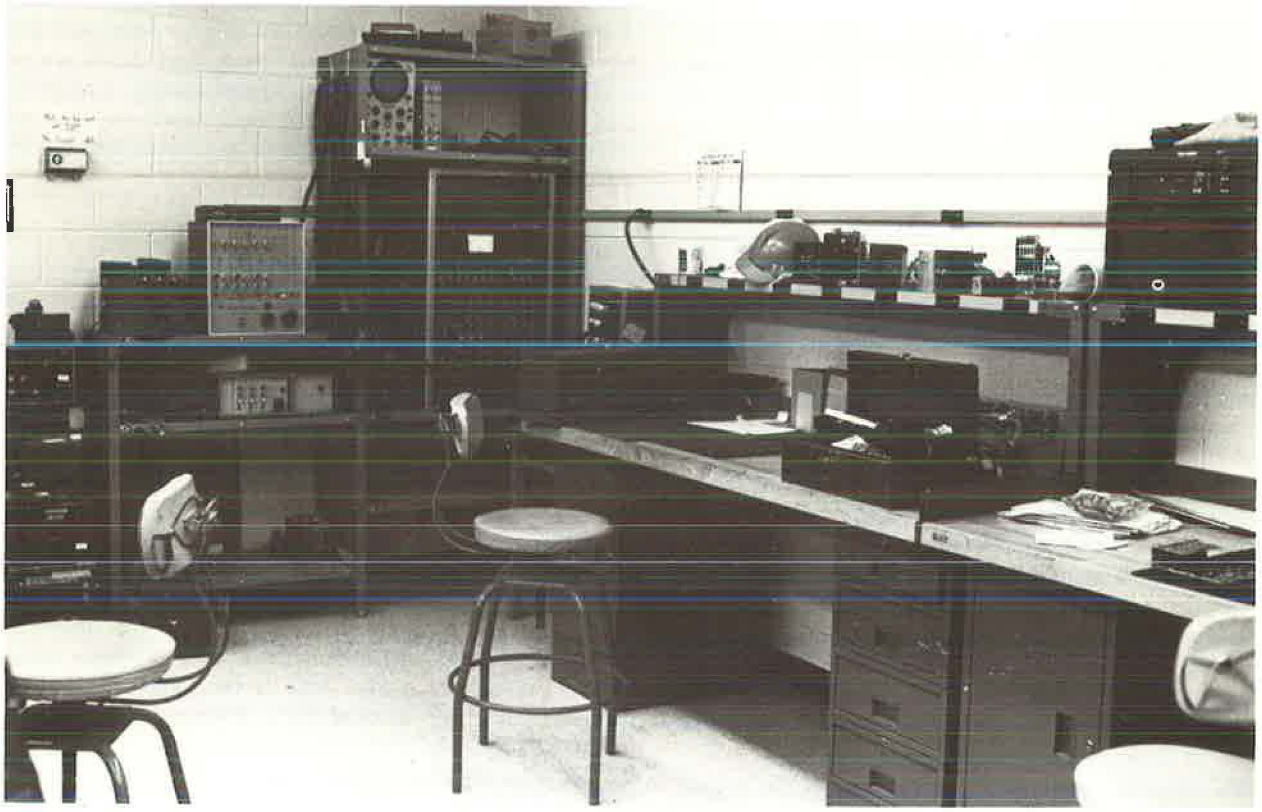

Figure 7. Signal repair shop.

Figure 8. Storage facilities.

Communications

Communications are required to initiate and coordinate the maintenance action, keep responsible officials informed, and coordinate personnel and materials.

Two-Way Radio

In nearly every jurisdiction, primary communications are by two-way radio. The number of frequencies used and the power of the transmitter are a function of the area to be covered, the radio traffic, and the availability of frequencies. Because frequencies in the land mobile, public service portion of the radio spectrum are in great demand, some jurisdictions have had difficulty in obtaining sufficient frequencies or permission to increase transmitting power. In those cases, every effort is made to control radio use and to create a clear channel when required for emergency communications.

Fixed remote radios may be installed at various signal maintenance offices and shops, or at the homes of supervisory personnel who may be called in off-duty hours. Mobile radios are installed in maintenance vehicles and in cars assigned to supervisory personnel. All employees using radio in the course of their duties should be well versed in correct radio communications procedure, and be instructed in the most efficient methods of originating and acknowledging messages.

Some jurisdictions also have battery-powered portable transceivers. These are used at locations where a temporary communications capability is required or may be used at job sites where personnel must work at some distance from their vehicles. All pieces of radio equipment should undergo a thorough preventive maintenance check at periodic intervals as recommended by the manufacturer and required by FCC regulations.

Other Communications Systems

In addition to conventional and hot-line telephones, teletypewriter is used occasionally between a central control facility and a maintenance contractor or to interconnect area control centers. Facsimile is sometimes used for these purposes. Jurisdictions covering large geographic areas, such as state highway agencies, may use microwave transmission between area headquarters.

Some jurisdictions report the use of citizens'-band equipment, or of walkie-talkie transceivers, during maintenance activities that require coordination. At least one jurisdiction has installed telephones in the cabinets of local controllers to facilitate coordination of the master-controlled system.

Warehouses and shops are usually provided with public address systems, paging systems, or other methods of internal communications.

Spares and Supplies

Many items are purchased and stored by the signal maintenance organization. The list of items depends on purchasing policies, delivery lead times, storage facilities, and the extent, type, and diversity of the signal system.

Furniture, Major Tools, and Equipment

Major power tools, furniture, and equipment used in the signal shop are permanent inventory items and their procurement or replacement must be individually justified and budgeted. The number of these items depends on the size of the system being maintained and the level of maintenance performed in-house.

Some jurisdictions have reported difficulties in convincing budgeting authorities of the need for procurement and replacement of these items. Although there are instances of quality homemade equipment, or equipment made to serve beyond the expiration of its normal service life, there are other instances where equipment deficiencies have led to less than optimum maintenance.

Signal Equipment and Parts

Signal equipment and parts include signal heads and sections; signal head parts, such as doors, gaskets, lenses, reflectors, and visors; complete controllers and parts thereof, such as phase modules, relays, and detector electronics; traffic signal posts, pedestals, and mast arms; detectors; and such miscellaneous items as handhole castings, cabinets, and cabinet parts (Fig. 9).

The number of items, and the quantity of each, depends on the size and diversity of the system being maintained, the replacement lead time for each item, and the average downtime for repairable items. The number of spares is set so as to ensure a fairly high probability of having a replacement unit available when needed. Many jurisdictions try to have spares available for immediate replacement. This means that they are usually carried on the maintenance truck. The sum of the spares so dispersed can, therefore, easily exceed the total number required for the entire system.

Another factor affecting number of spares is the diversity and interchangeability of control and detection equipment. Although most jurisdictions like to standardize on a given make and type of controller, procurement regulations do not always permit this. With a considerable number of competing manufacturers, each having approximately the same basic functional types of equipment, it is not unusual for a maintenance organization to stock spares and parts for several different makes of equipment.

Some maintenance organizations have been successful in constructing connecting cords and harnesses that permit interchange of some types of control equipment. Cooperation by manufacturers in standardizing control equipment, as is presently underway by the NEMA Traffic Signal Section, will greatly facilitate the maintenance task.

To a lesser extent, the problem also exists with traffic signal heads. Doors, lenses, reflectors, sockets, and gaskets are not always interchangeable between the products of different manufacturers. However, these items are less costly and take less storage space, so that the number of different replacement parts represents less of a problem.

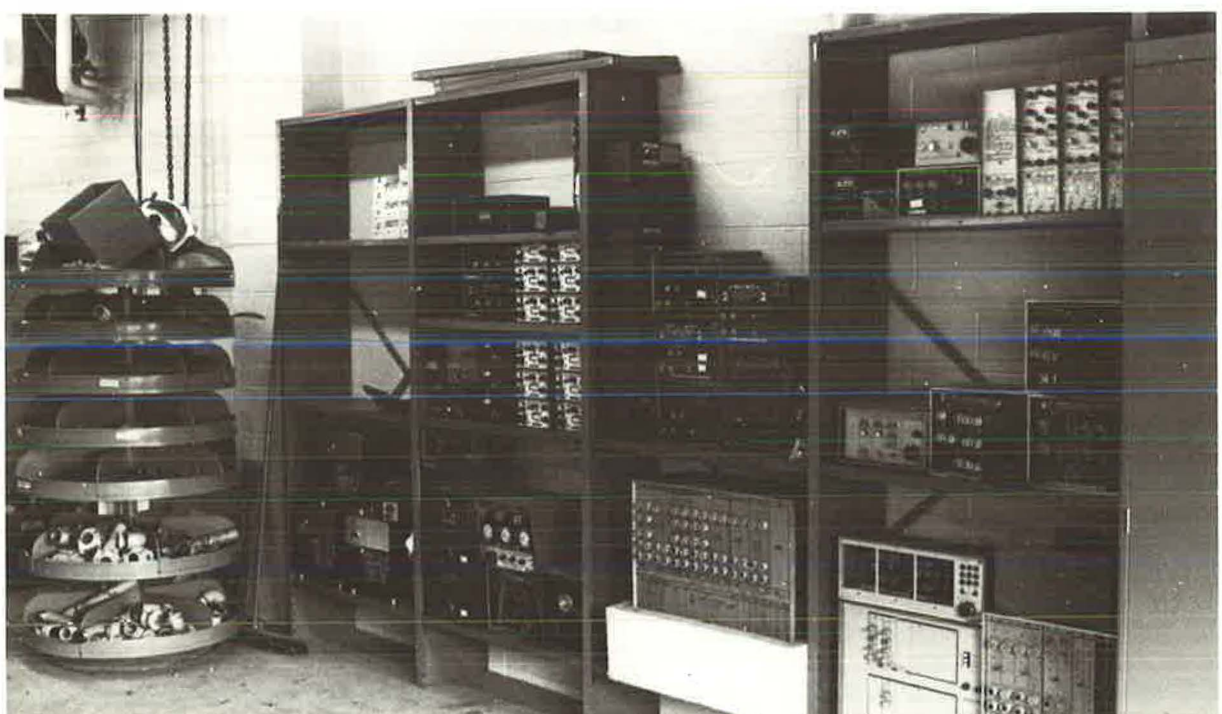

Figure 9. Spare parts.

Electrical and Mechanical Parts

Electrical and mechanical parts include all small electrical parts and components, hardware, cable, connecting wire, splicing material, conduit, and conduit couplings. Jurisdictions with a variety of signal types (including electromechanical, vacuum-tube, and solid-state types) keep a much greater number of parts than those that have a predominant type of control.

Because the number of different hardware items and electric components is so great (including all sizes and types of screws, bolts, washers, nuts, resistors, capacitors, transistors, and tubes), many jurisdictions do not even try to keep a complete inventory. Items that are difficult to procure or are in constant demand are stocked. Items that are readily available locally are purchased as needed. Maintenance experience, local availability, and purchasing policies will decide which items are stocked.

Maintenance Supplies

Maintenance supplies include cleaning materials, lubricants, paints, solvents, and similar items. Different signal head suppliers may make different recommendations concerning cleaning materials, although most maintenance organizations standardize on a cleaning procedure and material. The need for lubricants has correspondingly lessened with the decreasing use of electromechanical equipment.

Various types and colors of paint and primer are required for signal heads and posts, controller cabinets, and other equipment. A number of specialized solvents are needed for internal and external cleaning of control equipment. The recommendations of the equipment manufacturer and good maintenance practice should be followed.

Inventory

Inventory management requires that a determination be made of the desired level of each item, the point to which this level must sink before additional quantities are ordered, and the size of each of these orders. Proper choice of these levels will ensure an extremely low probability of ever running out of an item while minimizing inventory and procurement costs.

The prime determinant of inventory level is the expected use rate. Although some estimates of use can be made, the use rate for most items can only be determined on the basis of experience.

Printed Material

A complete up-to-date file must be kept of all printed material pertinent to the maintenance task, including reference books, codes, laws, manuals, standards, specifications, and catalogs. Some agencies provide repairmen with schematics, equipment data, and other material, and require them to maintain this information in a workbook.

CHAPTER THREE

TYPES OF MAINTENANCE ORGANIZATIONS

LOCATION OF SIGNAL MAINTENANCE FUNCTION

The responsibility for traffic signal maintenance work, and the administrative control over the personnel engaged therein, is located in different places within different agencies. Specific maintenance functions may also be assigned to different parts of an organization.

Within Traffic Unit

The most common location of the signal maintenance function is within a Bureau of Traffic or equivalent unit. It is customary for one engineer to have over-all responsibility for all traffic engineering functions, including planning, design, and operations. The signal maintenance function is usually found under operations.

Even where the actual maintenance is done by others, the traffic unit should retain over-all coordination and control. This is because the design of new installations and major reconstructions reflects maintenance experience so as to minimize future maintenance problems. To minimize adverse effects of signal malfunctions or breakdowns, the maintenance status of the signal system should be known. The traffic unit needs the maintenance history of individual installations as an input into the planning and programming of signal reconstruction work.

Within Maintenance Unit

Occasionally, the signal maintenance function is assigned to a maintenance unit. The primary reason for this assignment is similarity of duties and equipment used, especially in the nonelectrical work. This is somewhat more common with state highway agencies than with municipalities. Although the responsibility for signal maintenance at the state level may rest with a Bureau of Traffic, it is not uncommon to have maintenance work at a district level assigned to a Bureau of Maintenance, especially when there are only a few signal installations in the district or when the district does not have a full-time traffic engineer.

Location of the signal maintenance function within a Bureau of Maintenance may lead to a number of operating economies due to more efficient utilization of manpower and equipment, especially in those jurisdictions where the signal maintenance task is small compared to other highway maintenance work. On the other hand, it may impair the over-all coordination and control of the signal maintenance effort and may lead to difficulties if competing demands for the same maintenance resources exist. Several jurisdictions, recognizing this problem as well as the traffic engineering effects of highway maintenance work, have combined the traffic and maintenance functions into a Bureau of Highway Operations, which also may be assigned other related functions.

Within Electrical Services Unit

In recent years, municipalities and others have seen a considerable increase in the amount and types of electrical maintenance and construction. This includes traffic signals, street and highway lighting, pumping installations, fire alarm systems, communications systems, drawbridges, and electrical devices and distribution systems in publicly owned facilities. Because there are considerable similarities in requisite skills, materials, and equipment needed for the maintenance of these various systems, some jurisdictions have assigned over-all responsibility for some or all of these to an electrical services department or unit.

The organization of such a department may be arranged on functional lines (such as emergency repair, preventive maintenance, follow-up work), or it may be organized on system lines (such as signals, lighting), or it may have some combination of the two. The smaller the total systems to be maintained, the greater is the likelihood that individual members of the maintenance force will work on more than one of these systems. Although this may appear to be a maximally efficient utilization of manpower, it has the disadvantage that persons working on traffic signal maintenance may not have the high degree of skill and experience required for this task.

By Contract

Sometimes the maintenance function is performed by an outside agency under contract. Two types of contract have been identified. In the first, the contract is between two separate governmental organizations with overlapping jurisdictions. Thus, a city may maintain the signals installed by a state highway agency within its corporate limits or, alternatively, a state highway agency may maintain signals installed by a municipality. Reimbursement for this type of maintenance is usually on the basis of a flat annual rate, although time and material reimbursement contracts are also possible. With this arrangement, routine operating aspects of the signals, such as timing, are also performed by the agency having maintenance responsibility while the owning agency retains over-all control of signal phasing. In a somewhat similar arrangement, a small municipality may do routine inspection and field maintenance of its signal installations while depending on another jurisdiction for technical assistance and support. In one state, small municipalities and rural counties may take advantage of the facilities of the state highway department's central signal shop for any bench work required or for help in diagnosing signal malfunctions. This service may be free, or it may be charged for at a flat rate or on a time and material used basis.

The second type of maintenance contract is with a public utility or an electrical contractor. Although maintenance by a public utility is much more common for street and highway lighting, it has also been used for traffic signals in some jurisdictions, including at least one major city. A maintenance contract may cover all aspects of signal maintenance or only some parts thereof. Group relamping, painting, and bench repair of control equipment represent subsets of the maintenance task that lend themselves to performance under contract. Where new installations are constructed by outside contractors, a period of contract maintenance may be a part of the installation contract.

Other Arrangements

A number of other arrangements have been noted. In one jurisdiction, traffic signal maintenance work is the responsibility of the fire department because it is combined with maintenance of the fire alarm system. In another, signal maintenance work is done by a public corporation whose primary function is the installation, operation, and maintenance of a street and highway lighting system. In some small towns and villages with only a small number of signal installations, repair work may be done by the village electrician, who may be only a part-time employee.

Many different signal maintenance arrangements are possible. Some functions may be performed by one department, others by a different department, and still others by a department of a different governmental jurisdiction. Any arrangement can be supplemented by contract maintenance on a regular or standby basis.

RESPONSIBILITIES OF SIGNAL MAINTENANCE ORGANIZATION

The various work items that make up the signal maintenance task can be assigned to different parts of the organization.

Routine Inspection

Routine inspection of signal installations is usually done by the maintenance forces. However, many jurisdictions, because of lack of funds or manpower, make only sketchy inspections or no regularly scheduled inspection at all. Jurisdictions with a force that works only on traffic signals are usually in better position to schedule routine inspections. However, if this force is inadequate to handle emergency repairs and follow-up, or if it also has responsibility for a heavy program of signal reconstruction or new construction, the routine inspection task is usually the first to be neglected.

Where traffic signal maintenance is done under an all-inclusive maintenance contract, inspection becomes the responsibility of the contractor. The inspection interval and the type of inspection to be performed must be clearly spelled out in the contract. A great deal of trust must be placed in the maintenance contractor because verification of his inspection schedule is almost impossible. When the maintenance contract calls for immediate response at any time of day or night for any type of malfunction, without extra payment therefor, frequent and thorough inspections of all component parts of the signal system will be advantageous for the maintenance contractor.

Malfunction Detection

Malfunction reports are received from the police, from the maintenance force itself, from other agency employees, and from the public. Although the reporting of signal malfunctions should be the duty of every agency employee, the likelihood of a malfunction being detected and reported increases considerably as the degree of involvement with the signal maintenance function increases. An employee who works full time on signal maintenance is much more likely to detect a minor malfunction (such as intermittent detector failure, loss of coordination, or controller timing deficiencies), than one who has only limited or no involvement with traffic signals.

Traffic Signal Maintenance

The four major subdivisions of traffic signal maintenance (routine and preventive maintenance, emergency repairs, and follow-up work) are the responsibility of the primary maintenance organization. These four tasks may be assigned to different organizations or some may be done inhouse while others are done by contract. Thus, emergency repairs may be done by a maintenance force and follow-up work assigned to a construction crew that may not be in the same governmental agency.

The amount of routine and preventive maintenance being done varies widely from one jurisdiction to another. For instance, one jurisdiction reports that all control equipment is brought to the signal shop for checking and overhauling at intervals ranging from six months to one year. Another jurisdiction reports that no preventive or routine maintenance is ever done on control equipment and that this equipment is only brought to the shop upon actual failure. In the first jurisdiction the signal maintenance force is directly responsible to the Bureau of Traffic. In the second, signal maintenance is done by an outside agency. From this and other indications, it appears that the quality of signal maintenance improves as the signal maintenance forces are more closely related to the responsible traffic organization. Apparently, an appreciation of the operational implications of signal maintenance deficiencies could be translated into a sense of urgency when the same agency was responsible for both maintenance and operational aspects.

Traffic Signal Alterations and Construction

Traffic signal alterations, reconstruction, and construction may be done by the signal maintenance forces, by a separate construction division, or under contract. The procedure varies, depending on the kind and amount of work involved. For example, a contractor may install all conduit, handholes, foundations, and those detectors requiring paving work. On completion of this, the signal maintenance crew will install pedestals, heads, controller cabinets, and control equipment, and will wire up the intersection to make it operational.

Small jurisdictions are likely to have the maintenance forces responsible for signal alterations and reconstruction. Large jurisdictions are more likely to go to contract or to have a separate work force, which may report to the same department.

If this work is the responsibility of the signal maintenance forces, the scheduling of work and the setting of the proper priorities become essential. Although it is advantageous to do a signal reconstruction project as speedily as possible in order to minimize inconvenience to traffic, this must be balanced against the need to have crews available for normal and emergency maintenance work. This may require additional staff.

Jurisdictions with signal maintenance contracts may have minor signal alterations done by the maintenance contractor on a force account basis. One jurisdiction has recently changed its signal maintenance contract so that the contractor bids unit prices for common alteration and reconstruction items such as erection of temporary signals, changing of detectors, or adding of heads. The work is then done, at the agreed-upon price, as requested. Where this procedure is followed, the maintenance contractor is expected to have sufficient forces available so that normal maintenance work does not suffer when signal alterations or reconstruction work is being done.

The signal maintenance forces may play a major role in new construction, even when it is done under contract. In a number of jurisdictions it is their responsibility to procure, store, and test all equipment and components going into the new installation. They also may be charged with the responsibility of construction inspection, verification of quantities, and acceptance inspection and testing.

Other Maintenance

The signal maintenance forces may also have full or partial responsibility for maintenance of other systems.

Street, Highway, and Sign Lighting

The most common maintenance responsibility in addition to traffic signals is street and highway lighting systems. Except for control equipment, the work items involved in maintaining these two systems are quite similar. The equipment used for lighting maintenance can also be used for signal maintenance.

Fire Alarm Systems

Many signal maintenance forces also maintain fire alarm systems. In at least one jurisdiction, the fire alarm maintenance forces maintain the traffic signal system. In many jurisdictions cables in fire alarm ducts, or even spare conductors of multi-conductor fire alarm cables, are used to carry signal interconnection or system supervision communications.

Communication Systems

Except for leased telephone lines, all types of communications equipment may be maintained by the signal maintenance forces. If this capability exists, it is possible for the signal maintenance forces to be assigned the maintenance responsibility for other publicly operated communications systems. In a few jurisdictions this encompasses all communications equipment; in others, only that assigned to the traffic unit.

Pumping Installations

Maintenance of pumping installation power and control equipment is sometimes assigned to the signal maintenance forces. This may include the whole gamut of maintenance operations or only some parts thereof, such as inspection or routine maintenance. In some instances, the signal maintenance forces may be called upon to perform emergency repair work necessary to prevent imminent flooding conditions.

Buildings

Lights, power distribution, heating and ventilating, and other electrical equipment in public buildings are sometimes fully or partly the maintenance responsibility of the signal maintenance forces. It is common practice for the signal maintenance forces to maintain their own facilities, including shops, garages, and test equipment. Maintenance of other traffic unit facilities is also a fairly common procedure.

Other

Drawbridges, bridge navigation lights, airport runway and taxiway lighting, shop equipment, and many other items may be assigned to the signal maintenance forces in some jurisdictions.

CHAPTER FOUR

SIGNAL MAINTENANCE MANAGEMENT

Adequate maintenance of traffic signals represents a major expenditure of manpower, material, and funds. This requires a high degree of management control.

TECHNICAL CONTROL

Technical control of the maintenance work relates directly to proper operation of signal installations. It is, thus, of special importance that this control rests directly with that part of the organization responsible for signal operations.

Signal Timing and Phasing

Traffic signal maintenance is intended to assure that phasing, timing, and offsets are kept as close as possible to the values initially set by the traffic engineer. These data are kept in the files of the traffic department, in the files of the maintenance organization, and inside the controller cabinet.

It is not the function of the signal maintenance unit to make unauthorized changes to phasing, timing, or offsets. Therefore, it is advisable to develop a set of contingency timing and phasing plans covering potential malfunctions and breakdowns. These contingency plans should be developed by the traffic engineer and considered part of the permanent phasing and timing plans for the intersection. Furthermore, the traffic engineer responsible for operations should be informed whenever one of these contingency plans is activated.

Replacement of Control Equipment

Certain types of malfunctions and breakdowns require temporary replacement of the intersection control equipment. Replacement in kind (that is, with the same make and model) is the preferred and recommended procedure. However, this is not always possible. In jurisdictions with a great variety of control equipment, differing in both manufacture and function, it becomes a practical impossibility to stock sufficient spares to assure replacement in kind on a system-wide basis, let alone on every maintenance vehicle. Therefore, the traffic engineer must decide what type of replacement controller is to be used, considering the inventory of replacement controllers likely to be available. Some jurisdictions have developed for critical intersections contingency plans that call for borrowing an identical-type controller from a less critical location.

Inspection Frequency and Depth

Inspection frequency and depth should be based on the age and complexity of the equipment, the criticality of the intersection, and the past maintenance and operational history. In practice, however, the prime determinant of inspection frequency and depth is the availability of adequate manpower.

Some agencies have a checklist of the items to be covered during regularly scheduled inspections and keep a permanent record of the date of the inspection and the results (Fig. 10).

Maintenance and Repair Procedures

Detailed, formalized maintenance and repair procedures are developed and updated by the organization having responsibility for the actual maintenance work. These procedures cover preventive maintenance, troubleshooting, and emergency repairs.

Because maintenance is considered in the original choice of equipment, the design of the installation, and the development of specifications, maintenance and repair procedures should reflect these considerations.

"As Built" Plans

A record of the actual physical location of all component parts of a traffic signal installation, especially underground components, is essential for proper operation and maintenance of the installation. Although most jurisdictions retain the original construction drawings, relatively few try to keep these updated to reflect all field changes.

Changes often occur during construction, especially if detailed surveys of the location were not made prior to design. Changes also may occur after construction because of (a) relocation of service by the power company; (b) work at the site by private contractors, public utilities or others; and (c) as a result of maintenance work. The last may include replacement and relocation of conduit runs, use of spare conductors, and similar items.

"As built" plans are also required when major signal reconstruction or modernization is contemplated. Lack of these plans may lead to redesigns that are either difficult to execute or less than optimal in taking advantage of existing facilities.

Service Histories

Service histories of individual installations, signal systems, and types of equipment form the basis for planning, design, and maintenance decisions. It is therefore important that these be accurate, complete, and easily accessible. A service history (a record of maintenance work performed at a given location) is kept by nearly every organization performing traffic signal maintenance work (Fig. 11). However, vast differences exist among various jurisdictions in the completeness and accessibility of service histories.

The prime input into every service history is the records of individual maintenance actions. Some jurisdictions keep full documentation on every maintenance call, including routine inspections, preventive maintenance, and emergency work. These documents include the date, start and finishing time, any dispatching delay, a full diagnosis of the reported trouble, details of the work done, and the reason why it was done. Others keep only rudimentary records that often include no more information than the fact that a maintenance man was dispatched to a given location. The majority of service histories fall somewhere between these extremes.

Many jurisdictions keep fairly complete records for each intersection. These may consist of folders in which copies of all pertinent forms are kept, or they may be ledgers in which the information is entered for each location. Some agencies keep two files or ledgers so that maintenance histories are available on both an intersection basis and an equipment basis. This enables easy evaluation of the maintenance history of a certain class or type of equipment, or a specific model, and can be of considerable help in specifying new equipment or developing inspection or maintenance procedures.

Some jurisdictions do no more than file the reports on a chronological basis. This makes access to the records of a specific location almost impossible.

A few jurisdictions have computerized their service history procedures. All dispatching records, work orders, work order completion reports, trouble call reports, and inspection check lists are coded, keypunched, and entered into computer storage. They can be recalled in a convenient format when required. The number of jurisdictions using this procedure appears to be growing.

Policies on access to documentation by individuals outside the agency vary widely. The maintenance histories, or information on the maintenance and operational status of a given installation at a particular moment, are often requested by attorneys in connection with motor vehicle accident cases. Some jurisdictions make the records available as a matter of course, sometimes upon payment of a nominal fee; others will not relinquish them except under subpoena. A common practice is that the records are not made available but that responsible officials of the agency may be subpoenaed to appear and testify on the contents of the records. At least one jurisdiction has deliberately limited the amounts of information kept in the files so as to minimize the time spent in court by its employees.

MATERIAL CONTROL

Effective management requires that close control be exercised over purchasing, storage, and distribution of the many items used for traffic signal maintenance.

Inventory Control

Inventory control is necessary to assure that material, equipment, and supplies will be available when required and that material use is proper. The manner in which inventory control is exercised depends on the size of the system being maintained and on the administrative structure and policies of the maintenance organization.

Inventory control, especially in the larger organizations, is increasingly being computerized. When this is the case, it is often combined with reorder procedures (Fig. 12).

Two methods of inventory control can be identified, although both make additions to inventory as received. Subtractions from inventory are made on the basis of withdrawal records in one method and on the basis of use records in the other. In the withdrawal method, the inventory level is reduced whenever an item is physically withdrawn from stock, regardless of whether it is to be used for a specific job, added to the inventory carried on a maintenance truck, or available at a work site. This method has a tendency to understate total inventory, but is capable of

ANNUAL TRAFFIC SIGNAL INSPECTION REPORT

Intersection Location ________ Co. ________ Route ________ Section ________
Power Company ________ Date ________
Terminal Voltage ________ Time ________ AM ________ PM
Bulb Count ________ 60W ________ 100W ________ 150W Changed ________
CONTROLLER: Type ________ Serial No. ________ BT No. ________
Interconnection Unit ________ Box Type ________ Detector Circuit Voltage ________
Accessory Controls: DR5 SR4 MC3 MM2 MM3 S-4 S-3
RADAR UNITS PRESSURE DETECTOR
Serial Nos. ________ ________ ________ ________
Sensitivity Voltage Output ________ ________ ________ ________
Sensitivity Opposite Direction Voltage ________ ________ ________ ________
Resistance Open Circuit Ohms ________ ________ ________ ________
Choke Coil or Condenser ________ ________ ________ ________
Resistance Closed Circuit Ohms ________ ________ ________ ________
Roadway Height ________ ________ ________ ________
Size ________ ________ ________ ________
Type ________ ________ ________ ________
SIGNAL HEADS:
Type ________ ________ ________ ________
Quantity ________ ________ ________ ________
Size ________ ________ ________ ________
Make ________ ________ ________ ________
ACTUATED CONTROLLER:
Timing Dials Check ________ ________ ________ ________ ________ ________ ________ ________ ________
Relay Operation ________ Line Switch Operation ________ Detector Relay ________ Filter Operation ________
Manual Cord ________ Fused Properly ________ Chattering Relays ________ Replaced ________
FLASHER:
Motor Disc Torque ________ Contact Condition ________ Bearing Adjustment ________
Fused Properly ________ Filter Operation ________ Replaced ________
SIGNAL RELAY:
Chattering Relays ________ Contact Adjustment ________ Contact Screws Tight ________
FIXED TIME:
Timing Dial Operation ________ Key Pin Operation ________ Reset Ciruicit ________ Manual Cord ________
Cam Shaft & Bearings ________ Cam Motor & Brake ________ Contact Adj. ________ Cam Lobe Adj. ________
PRESSURE DETECTORS:
Detector Frame ________ Hand Hole Cover ________ Pressure Pad ________
SIGNAL HEADS:
Painting ________ Clean Lense ________ Clean Reflector ________ Head Adjustment ________
Head Line Up ________ Upper & Lower Bracket ________ Tightened ________ Door Lock ________
Door Hinge ________ Door Gaskets ________ Angle Hoods ________ Head & Hanger Lead Washer ________
Signal Head Repair ________
GUY WIRE: ________ ft. Condition ________ Guy Clamps ________
INSULATORS: ________ Quantity Service Sleeves ________ Eye Bolts ________ Utility Clearance ________
ANCHORS: ________ Quantity Down Guy Condition ________ Guy Clamps ________ Service Sleeves ________
Insulators ________ Eye Bolts ________
CLEVIS & INSULATORS: ________ Quantity Thru Bolts ________
POLES: ________ Wood ________ Steel Rake Angle ________ Utility Clearance ________
Anchoring ________ Deterioration-Splitting ________ Painting ________ Grouting ________
Pole Caps ________ Hand Hole Covers ________ Bolt Covers ________
WIRE: Roadway Clearance ________ Condition ________ Splice Loops ________ Taped Joints ________
Insulation Resistance ________
CONTROL BOX:
Tighten Wire Terminals ________ Proper Grounding ________ Control Cable Condition ________
Police Panel Switches ________ Air Vent ________ Door Lock & Gasket ________
Box Mounting Bracket ________ Constant Voltage Regulator ________
S - Satisfactory
R - Bad But Repaired
X - Bad But Not Repaired

SIGNED: ________
FOREMAN LEADMAN

cc: District Engineer
Resident Engineer
Original to Electrical Engineer

Figure 10. Inspection check list and record.

Form No. DT 851 (Rev.)

DEPARTMENT OF TRAFFIC
City of Los Angeles

TIMER RECORD CARD DEPT. SER. NO.

TYPE TIMER ________ IN SERVICE DATE ________ MFG. SER. NO. ________

Date Issued	Date Installed	INTERSECTION	Date Removed	TROUBLE	REPAIRS MADE	By	Date Repaired

Figure 11. Service history.

fairly easy verification by physical checks at a limited number of sites.

With the use records method, subtractions from inventory are made on the basis of the bill of materials included with work order completion reports. This method gives a more accurate picture of the inventory on hand, but requires complicated procedures for verification. The preparation of detailed bills of materials, especially if these have to include a great number of small expendable items, places an extra burden on the maintenance personnel in the field and usually gives rise to inaccuracies. It is, however, a tighter control against pilferage and waste.

Reorder Procedures

Control over reorder procedures consists of assuring that approved policies are followed, that funds are available, and that type, quantity, and delivery conform to requirements.

With the long lead times required for delivery of some types of items, it is not unusual that orders have to be placed before the previous order for the same item has been delivered. This requires close control so that the correct quantity is ordered at the correct time.

Purchasing Requirements

In many jurisdictions, adequate control of purchasing represents one of the most difficult problems in traffic signal maintenance management. The problem is one of finding a suitable trade off between technical adequacy, maintainability, quality, reliability, and delivery schedules on one hand and cost on the other.

Some jurisdictions have found an equitable solution to this problem in which all pertinent factors are considered. In others, however, one or the other side is dominant, with adverse effects on the maintenance task. The most common case is where purchases must be made only on a low bid price basis. The maintenance organization may not have sufficient input to assure optimal purchasing. This is especially true in those jurisdictions that do not consider maintainability or compatibility of spares and test equipment in the purchasing process.

Development of optimally cost-effective purchasing requirements depends on close and sincere cooperation between those responsible for signal operations, signal maintenance, purchasing, and budgeting with a full understanding by each of the problems and constraints faced by the others.

ADMINISTRATIVE CONTROLS

Good traffic signal maintenance practice requires that tight control be exercised over all work resources. The need for tight controls is even more important where the maintenance function is separate from the operating unit.

Work Order Completion Reports

In order to exercise full control over the maintenance effort, the maintenance organization must have complete information on how the work was actually done; when it was done; by whom; and the resources used. This information, in the form of work order completion reports (Fig. 13), serves as input data for the preparation of "as built" plans and service histories. The reports confirm completion of work and restoration of service, and may be critical when officials are required to give testimony in court.

Detailed analysis of work order completion reports in conjunction with service histories can yield much valuable information. The analysis will help to determine the total impact of malfunctions and breakdowns and to make economically valid decisions concerning equipment replacement, intersection reconstruction, or changes in design, construction, or maintenance practices. Analysis of work order completion reports, in conjunction with analysis of reports on routine maintenance operations, serves as a check and guide for optimal maintenance resource allocations.

The work order completion reports are usually prepared by field maintenance crews, checked by a foreman or other supervisory personnel, and transmitted to the headquarters of the organization having maintenance responsibility. Because the information contained in these reports will have a bearing on current and future operational aspects of the signal system, it is important that copies of these reports also be routed to the signal operations unit.

Material Reports

It is important to keep track of the material used on specific maintenance assignments. One reason is the possibility of relating material use to maintenance levels. This type of correlation assists in setting optimum inventory quantities and adjusting these as maintenance levels, system size, or system age changes. The amount of materials used on similar projects by different crews can serve as a check on crew efficiency.

1840-001 TRAF GENERAL STORE — DAILY WAREHOUSE ORDER ACTION REPORT — 09-14-72 — PAGE 1

CLASS CODE	STOCK NO.	DESCRIPTION	**ACTION** DATE TO ORDER	A T	STATUS ON HAND	RESERV	AVAIL	MIN	MONTH USAGE	ON-ORDER ORDER QNTY.	DATE ORDERED	REF-NO	ORIGINAL E.T.A.	REVISE E.T.A.
07K	0271 330	FUSE MDL 3 SLO-BLO	09-05-72		3	0	3	6	3.0					
26A	0418 781	BATT PENLITE SIZE AA ALKALINE	09-14-	*	12	0	12	0	.0					
26B	0262 269	BATTERY STRGE 12V GR 48 AH 170	09-05-	*	0	0	0	0	.5					
26D	0127 035	HYDROMETER BATTERY	09-05-	*	0	0	3	2	.6	3	08-31-72	220467	10-15-72	
27A	0262 293	CLOROTHENE SPRAY AEROSOL CAN	09-11-72		65	0	65	70	23.6					
28B	0101 184	BLEACH LIQUID	09-12-72		5	0	5	7	3.2					
28F	0101 400	SOAP MECHANIC'S BORAXO POWDER	09-01-72		25-	0	25-	20	9.3					
28G	0101 060	DISPENSER FOR FOLDED PAPER TOWEL	08-24-	*	0	0	3	1	.2	3	08-22-72	220434	10-06-72	
28I	0466 794	CHAMOIS SYNTHETIC 18X21 IN	08-15-72		0	4	4-	4	1.3					
29C	0267 953	VEST SAFETY RED LGE	08-11-	*	1-	0	79	24	8.3	80	09-09-72	002603	09-23-72	
31A	0290 378	COOLER WATER 3-GAL SS W/SPIGOT	08-28-	*	0	14	4	6	2.2	18	04-12-72	016466	05-07-72	09-29-72
33B	0294 225	TERMINAL API 320559	08-14-72		3	0	3	15	1.2					
33B	0291 560	TIE CABLE NYLON 6-3/4 IN	06-13-72	*	2299	0	2299	3315	1123.7					
33C	0268 380	BUSHING GRD GALV BONDING 2	09-05-	*	0	400	400	85	39.3	800	08-31-72	003590	09-29-72	
33C	0268 097	COVER FOR 3/4" CONDLT 601LB/T01T	09-07-72		28	0	26	50	20.2					
33D	0271 462	HOLDER FUSE BUSS # HEB	08-22-72		20	0	20	26	12.6					
33E	0105 732	LAMP TRAF SIG- 69 A21/TS-69W	- -		11982	0	32022	6550	3434.5	20040	08-22-72	220431	10-06-72	
33E	0512 338	LAMP MINIATURE 28V .04AMP	05-30-	*	0	0	0	0	.0					
33I	0298 247	WIRE HOOK-UP NO 14 BLK STRANDED	08-15-72		0	0	0	349	104.1					
33I	0511 676	WIRE HOOK-UP NO 18 BLK STRANDED	- -		2000	0	3000	210	64.9	1000	09-12-72	020433	10-11-72	
33I	0294 667	WIRE HOOK-UP NO 18 RED STRANDED	08-28-	*	0	1000	4000	940	433.7	5000	08-24-72	003400	09-18-72	
33I	0294 675	WIRE HOOK-UP NO 18 WHI STRANDED	08-28-	*	0	0	5000	750	323.3	5000	08-24-72	003400	09-18-72	
33I	0294 691	WIRE HOOK-UP NO 18 YEL STRANDED	09-01-72		0	0	0	675	207.9					
33I	0305 294	WIRE TYPE B 600V 18GA	08-15-72		3000	0	3000	3135	963.1					
33I	0305 324	WIRE TYPE C 1000V 14GA BLACK	08-28-	*	0	0	5000	675	207.9	5000	08-24-72	003400	09-18-72	

Figure 12. Computer inventory printout.

DT 340
CITY OF LOS ANGELES
DEPARTMENT OF TRAFFIC

SUPPLEMENTAL REPORT BY FIELD CREW

1 REPORT NO.

2 LOCATION

3 DATE:

4 TYPE REPORT:
☐ ACCIDENT
☐ NON-ACCIDENT
☐ CONTRACTOR DAMAGE
☐ INFORMATION

5 TIME CALL RECEIVED | TIME ARRIVED | TIME CLEARED

6 CONDITION: ☐ DARK ☐ STRUCK ☐ FLASHING ☐ OPERATING

7 POLICE: ☐ ON SCENE | UNIT NO. | ☐ CALLED ☐ DID NOT ARRIVE

8 NOTIFIED: ☐ CONTROL 1 ☐ FOREMAN ☐ RAILROAD ☐ OTHER .... TIME:

9 CAUSE OF DAMAGE
Name
Address
Others License No.

10 T S R No. Truck No. Hours
Signed Hours
(person submitting report)

11

EQUIPMENT	DAMAGED	DOWN	TYPE
CABLE			
CONDUIT			
CONTROLLER			
FOUNDATION			
HEAD(S)			
MAST ARM			
PED HEAD			
SIGN(S)			
STANDARD			
ST. LIGHT			

12 CHECK LOCATION

N

13 MATERIALS NEEDED FOR REPAIRS

14 LEFT SCENE, INTERSECTION WAS: ☐ OPERATING ☐ ON FLASH ☐ OFF

15 ADDITIONAL INFORMATION:

16 SALVAGE TO: ☐ CENTRAL ☐ VALLEY ☐ WLA ☐ SP

17 **REPAIR SECTION**

18 DATE OF REPAIRS:

19 WORK DONE: ☐ ASSISTED ☐ REPAIRED ☐ REPLACED ☐ PICKED UP

20 WORK DONE BY: ☐ TSR ☐ CONST. ☐ SIGNAL SHOP ☐ SIGN CREW ☐ WRECK CREW ☐ CEMENT CREW ☐ PICKED UP CREW

21

CREW NAMES	TITLE	CREW NO.	HOURS

22

MATERIALS USED	STOCK NO.

23

TRUCK AND/OR EQUIPMENT NUMBERS	HOURS

24 WORK STILL REQUIRED BY: ☐ CONST. ☐ SHOP ☐ SIGNS ☐ CEMENT ☐ ST. LIGHT ☐ PICK UP ☐ OTHER..................

25 ALL REPAIRS COMPLETE ☐ YES ☐ NO

26 SIGNED:
(person making repair section report)

27 INFORMATION OR COPIES TO

☐ WRECK TRUCK	☐ CONSTRUCTION	☐ SHOP	☐ SIGNS	☐ OTHER..........
date	date	date	date	date
name	name	name	name	name

Figure 13. Work order completion report.

DT 511 (2R 6/71) MS
City of Los Angeles
Department of Traffic

DAILY WORK SUMMARY
TRAFFIC SIGNAL
PROGRAMMED MAINTENANCE

Hours Worked ______
End Miles ______
Start Miles ______
Total Miles ______

Date ______ Name ______

Units	SIGNAL ABOVE GROUND MAINTENANCE (2345)		Units
	Heads, install or remove	Stiffeners, install or remove	
	Heads, replace	Stiffeners, replace	
	Heads, repair or adjust (2876)	Stiffeners, repair or adjust	
	Backplate, install or remove	Thru bolts, install or remove	
	Backplate, replace	Visor or louvre, install or remove	
	Backplate, repair or adjust	Visor or louvre, replace	
	Ped heads, install or remove	Visor or louvre, repair or adjust	
	Ped heads, replace	Overhead, repair or adjust	
	Ped heads, repair or adjust (2876)	Standard, repair or adjust	
	Push buttons, install or remove	Others, explain	
	Push buttons, replace		
	Push buttons, repair or adjust		

Units	SIGNAL MAINTENANCE INSPECTION (2157)	SIGNAL UNDERGROUND MAINTENANCE (2301)	Units
	Work by contractor	Repair cable	
	Mark out	Replace pull box lid	
	Prepare conduit run diagram	Replace pull box	
	Inspect, check, trouble shoot when no work is required	Replace detector pad	
		Pull cable (each 10')	
	Meet engineer, contractor, etc.	Other, explain	
	Fill out Completion Notice, Update Form		
	Check intersection for Accounting		
	Others, explain		

Units	CONTROLLER FIELD MAINTENANCE (2356)		Units
	Install or remove:	Replace:	
	Decoder	Decoder	
	Synchronizer	Synchronizer	
	Encoder	Encoder	
	Sensor	Sensor	
	Relay	Relay	
	Fan	Fan	
	Clock	Clock	
	Timer	Timer	
	Dial	Dial	
	Entire controller	Entire controller	
	Others, explain	Others, explain	
	Repair, Adjust, Tone:		
	Decoder	Connect interconnect	
	Synchronizer	Connect telephone interconnect	
	Encoder	Connect fire alarm interconnect	
	Sensor	Disconnect interconnect	
	Relay	Change timing	
	Fan	Prepare timing charts	
	Timer	Put back charts-plans-card-etc.	
	Dial	Hook up loops	
	Others, explain	Others, explain	

PREVENTIVE MAINTENANCE:
(3681) Electrician Check List---Number of hours worked this day ___ Number of I/S Completed ___
(3694) Electrical Helper Check List-Number of hours worked this day ___ # of I/S Completed ___
(3983) Perform Operational Check on Signal System: Completed: No. of I/S
Name of System ______ Yes__ No__ Checked: ___
Relamp Burnout: 8" (2746) ______ 12" (2810) ______ Other (2835) ______
Supervision (0135) (hrs) Clerical, General (0429) (hrs)

OVERHEAD TIME (Explain):	Hours
(8261) Inclement Weather	
(8276) Delay, Field	
(8293) Delay, Yard or Shop	
(8463) Tool and Vehicle Maintenance	
(8491) Training	

Figure 14. Labor record – work summary.

Another important material control is the assurance that specifications are being met. This may be done by an acceptance testing program and/or by a review of the supplier's quality control.

An indication of quality can be obtained from reports of premature or unusual material or equipment failure.

Labor Records

Many jurisdictions report that they are short of manpower. Therefore, it is essential that the available manpower be utilized as effectively as possible. Detailed analysis of labor records (Fig. 14) can indicate the portions of time spent on work, travel, and standby. This may indicate that increases in efficiency could be obtained by rearranging shifts, area assignments, routings, dispatching procedures, and other aspects of personnel assignment. Comparison and analysis of the time spent on individual maintenance assignments may indicate that changes in procedures, changes in equipment assignment, or changes in crew size or composition may lead to an increase in efficiency.

Equipment Records

An accurate record should be kept on total use of any piece of equipment so that normal preventive maintenance operations, as well as replacement, can be optimally scheduled.

Analysis of equipment records permits a rational decision to be made as to the number and type of each class of equipment needed and whether to buy or lease. This analysis will also reveal whether shared-use arrangements with other governmental units serve the best interests of the maintenance organization.

Detailed equipment records facilitate the task of justifying purchase of major pieces of equipment.

FISCAL CONTROLS

Fiscal controls are an integral part of good management practice. More than any other type of control, they are usually mandated and fairly narrowly prescribed by government-wide administrative regulations. In many jurisdictions they are even prescribed by laws and ordinances.

Cost Accounting

Cost accounting assigns monetary terms to the manpower, equipment, materials, and supplies. The result is a total cost figure for each maintenance operation. These cost figures represent an extremely valuable management tool in optimizing maintenance operations.

Cost accounting procedures can also support service histories to determine when installations should be scheduled for reconstruction or when certain classes of control equipment should be withdrawn from service.

Cost accounting is required in those jurisdictions that receive reimbursement from outside sources for part of their signal maintenance activities. This is the case where one governmental unit maintains all or part of a traffic signal installation belonging to another. Reimbursement for this work may be on an actual cost basis, which mandates accurate cost accounting, or on a flat-rate basis. In the latter case, cost accounting is necessary so that equitable rates can be developed and adjusted as necessary.

Budgeting

Budgeting procedures for the signal maintenance function are no different from those of other governmental units. Preparation of preliminary budget estimates follows a similar pattern: the previous period's budget figure for each line item is adjusted on the basis of the most recent experience. The records discussed in previous sections are essential to this task.

Many jurisdictions continue to report that their existing budgets are insufficient for adequate signal maintenance. This requires trade offs and usually leaves some needed work undone. The budgeting process is thus complicated by the necessity of committing funds to make up for past inadequacies, knowing that this, in turn, will create future inadequacies.

Another factor may complicate the budgeting process. In some cases, the budgeting function remains with the traffic signal operating agency although the physical maintenance work is delegated to another governmental unit. Close cooperation is required between the two agencies to prepare a realistic budget.

Invoices

Procedures for verification and approval of invoices are usually fairly well set and are a part of the general administrative procedures. A problem may arise from separation between the operating and maintenance agencies. If this condition exists, a viable system of double approval may have to be developed.

Emergency purchase orders are extremely useful and may be considered almost essential for effective accomplishment of the maintenance task. However, unless extremely tight control is exercised this procedure can easily be abused. Excessive use of emergency purchase orders to bypass the normal purchasing process can exhaust emergency funds.

Payroll

Field maintenance men, by the nature of their duties, generally work on their own, away from a definite assigned place, and without regular and constant supervision. Abuses can easily arise under these circumstances unless firmly checked.

There also have been reports of abuses of overtime. This is especially hard to police in the case of nighttime call-outs where the maintenance man leaves from and returns to his home. Spot checks by supervisory personnel, as well as close correlation of time sheets, work order completion reports, and radio logs, can minimize this abuse.

Because labor represents the single largest component of total costs, tight controls can be extremely productive. They are absolutely essential if operating under funding restrictions. It must be kept in mind, however, that it is easy to overcontrol the work force, thus leading to inefficient use of supervisory personnel and resulting in a loss of employee morale, efficiency, and initiative.

CHAPTER FIVE

FINANCES

The financial aspects of traffic signal maintenance can be divided into three broad areas: the unit costs of the individual maintenance tasks; the total cost of maintaining a signal system; and the sources of the funds.

UNIT COSTS

It would appear to be a simple assignment to attach a cost, or at least a range of costs, to each of the resources required for signal maintenance. If this could be done, calculation of unit costs (cost per intersection) would be easy and determination of total maintenance costs would be reduced to a simple exercise. In practice, however, the problem is far more difficult. This is primarily due to an almost universal lack of proper cost accounting procedures, complicated by an almost equally widespread failure to keep adequate records.

This failure extends even to such cases as material, equipment, and supplies with known unit prices. For "big ticket" items, such as signal controllers or major pieces of shop equipment, the original purchase cost usually is known. However, from an accounting point of view, many problems exist even for these items. For instance, it is common accounting practice to depreciate capital goods according to some rule that will spread the net cost of an item (purchase price less salvage) over its useful life.

For traffic signal controllers, however, the useful life is not known. This is only partially due to a lack of records. Signal control technology is changing so rapidly that many types have not been in service long enough for a life determination to be made; as a matter of fact, most signal controllers become functionally obsolete before they are worn out mechanically. Such obsolete equipment is usually retained as spares, installed at less critical locations, or cannibalized for parts. None of these procedures allow for a definite determination of either service life or salvage value.

The situation is even more critical for less costly small parts and supplies. These are usually purchased in bulk, warehoused, and withdrawn from stock as needed. Some jurisdictions attempt to control material of this kind by assigning each withdrawal to a particular location. Few agencies account, on an intersection basis, for bulk supplies such as cable and wire, electrical tape, paint, etc. At best, the total costs of these items are determined on a system-wide basis for an entire year and spread evenly over the system. This procedure ignores the fact that some intersections have greater maintenance needs than others.

Even worse, from an accounting point of view, is the fairly common practice of lumping inventories for signal work with other electrical work that may be the responsibility of the signal maintenance organization.

Shop, field, and communications equipment costs are usually assigned system-wide and charged to overhead. The basic difficulty with this procedure is that, unless accurate records are kept for a considerable time and carefully analyzed, it becomes impossible to relate these overhead costs to the size, composition, and age of the signal system, or to the level of maintenance. If any sharing occurs—and this is the rule rather than the exception, especially in smaller jurisdictions—the allocation of costs is more difficult.

Another problem is the accounting of labor costs. The cost that should properly be charged to a specific maintenance assignment is the true hourly rate of the person engaged in the maintenance task multiplied by the time actually charged to the job. To this must be added a proportionate amount of the total travel and other nonproductive time of the employee. Another problem involves the time allocation of supervisory personnel, working foremen, technicians, and engineers, who may switch from signal maintenance to signal operations to signal design to other traffic engineering or administrative functions with no clear idea of how much time is spent on each function.

The unit costs of signal maintenance can be clearly assessed where the entire maintenance task is done by contract, because the contracts are usually bid on the basis of monthly or annual charges for each signal head, detector, controller, etc., actually maintained. There is some inaccuracy involved in this process because the cost of maintaining underground and overhead facilities, cable, and conduit is included in the maintenance costs of the components. This is not as critical as proper allocation of the time of administrative and technical personnel assigned to supervision of the maintenance contract.

The data collection effort for NCHRP Project 3-20, "Signal Warrants," included nationwide mailing of a comprehensive questionnaire dealing with all aspects of current signalization practices. One of the questions dealt with construction, operations, and maintenance costs.

Of the 215 replies received, only 92 of the respondents tried to answer all or part of the question dealing with maintenance costs. Many of the respondents who did not answer this question added notes to the effect that determination of these costs was either impossible because of lack of the proper records, or would represent such a time-consuming task that it could not be attempted. The responses for average annual maintenance cost per intersection ranged from $10.50 to $2,100, with most less than $200. Costs in cities were generally lower than those of states and counties.

One eastern suburban county that has all its maintenance done by contract paid a total of $587,000 in a two-year period for complete maintenance of a system consisting of 1,200 signalized intersections, 100 floodlights, 100 parking meters, and 50 miscellaneous electrical devices. New York City has in excess of 9,000 signalized intersections maintained under a number of contracts that total $4,500,000 annually.

TOTAL COSTS

The total cost of maintaining a signal system includes the sum of the intersection unit costs (mentioned previously) plus other direct costs and expenditures for overhead and capital.

Direct Costs

The direct costs of signal maintenance include the labor, parts, and supplies required to do the actual maintenance work. This also includes those items of direct costs (such as shop work) that cannot be charged to a specific intersection. When signal reconstruction work is performed by the signal maintenance forces, at least part of the costs will be direct maintenance costs; the rest will be a separate budget item.

Overhead Costs

Overhead includes all costs that cannot be assigned directly to the maintenance of specific components of the traffic signal system. In determining the true maintenance costs of individual installations these overhead items must be spread through the system by some consistent method, usually as a percentage of direct costs.

Overhead costs cover a number of different items. Some of these, such as clerical and administrative help, are almost independent of system size; others, such as cleaning and lubricating material, are sensitive to changes in system size. Furthermore, some of these component parts will change linearly with system size, others may change as a step function. Other important factors that may affect the magnitude of overhead costs include age and composition of the system and changes in levels of maintenance.

Other overhead costs include patrolling and routine inspections where the time spent at any one location is not enough to allocate; operation of the signal shop, warehouses, offices, and other physical plant of the maintenance organization; costs of supervision and administration; training; and vacation and sick pay. In some agencies, fringe benefits (retirement, health insurance, etc.) are charged to overhead.

The best accounting and budgetary control is achieved when overhead costs are kept to an irreducible minimum; that is, when as much as possible of the total budget can be allotted to specific intersections or to system-wide direct costs. This is not as much a function of how the funds are expended as it is of how the records are kept.

Determination of overhead costs may be more difficult where services are shared by various governmental departments or where administrative functions are centralized.

Capital Items

Many agencies make no distinction between expendable supplies and capital items. This may seriously distort the true cost of maintenance in a year when a major item (e.g., a $30,000 platform truck) is purchased.

Although true depreciation accounting is rarely employed by government agencies, several other mechanisms have been developed. The simplest of these is separate expense and capital budgets. Although this is a fairly common practice, a number of jurisdictions reserve the term "capital" for buildings and other construction items. Even if this is not the case, this separate budget procedure has the tendency of suppressing de facto increases in true maintenance costs attributable to an increase in the size and replacement costs of the physical plant.

Some jurisdictions have established sinking or revolving funds. These consist of annual appropriations to a fund that is used to replace equipment as needed. This procedure seems to work out fairly well unless there are abrupt changes in the size of the equipment inventory.

Several jurisdictions lease major equipment instead of buying it. This may be a true lease with a commercial supplier, or it may be a paper transaction with another government agency acting as lessor. The exact procedure used is less important than the recognition that depreciation of capital equipment is a proper part of signal maintenance costs.

SOURCES OF FUNDS

Funding for traffic signal maintenance is usually by appropriation from general revenue. In a number of jurisdictions income from motor fuel taxes, driver licenses, registration fees, etc., is dedicated to highway use, including signal maintenance. Except for rare natural disasters, agencies do not use borrowed funds for signal maintenance. Although federal-aid funds cannot be used directly for maintenance, there is a derivative effect because use of these funds for construction may make local revenues, which would otherwise have been used for construction, available for maintenance.

State aid to local governmental units is common, and in many cases represents the biggest single source of signal maintenance funds. These aid funds may come from general revenue, but much more often are a legally mandated portion of dedicated funds (usually motor fuel tax receipts), apportioned to cities and counties according to a prescribed formula. State aid for signal maintenance may also take the form of direct assumption by the state of the maintenance responsibility for locally owned signal installations.

CHAPTER SIX

CONCLUSIONS

The management of traffic signal maintenance has a major effect on public safety and convenience. Deficiencies in maintenance lead to signal malfunctions or breakdowns that cause delays to the traveling public, increased accident potential, increased fuel consumption, and increased air pollution. Thus, it is important to have a signal maintenance program that includes not only a procedure for quick response to emergencies, but also routine and preventive maintenance to ensure that lamp burnouts, detector malfunctions, controller problems, etc., are kept to a minimum.

An important factor in the maintenance management of traffic signal equipment and systems is location of the signal maintenance unit within an organization. The most logical location is within a Bureau of Traffic or equivalent unit. Thus, the same organization that has responsibility for operations also is responsible for maintenance, and close coordination and cooperation is possible. Where maintenance is not within the traffic unit, regular inspection of traffic signal installations is rare. This is also true where maintenance is performed under contract.

The ideal maintenance program provides full 24-hour service. However, this usually is not feasible and some system for standby or on-call crews is used. Because signal maintenance is a function affecting public safety, each person engaged in it should consider himself on call at all times, similar to policemen or firemen.

Many signal maintenance employees are highly trained and skilled electricians or electronic technicians. Maintenance organizations compete in the job market with electrical contractors, utility companies, and electrical manufacturers; therefore, they must pay prevailing wage rates if they are to retain their employees.

"As built" plans and service records are essential to efficient operations of the traffic organization. The "as built" plans make it easier to locate all the component parts of a signal installation, especially underground components. Service records are used to make planning, design, and maintenance decisions and must be accurate, complete, and easily accessible.

Maintenance costs play an appreciable role in any decision to change, reconstruct, or replace signal installations. If these costs are not known accurately, it may not be possible to obtain the maximum benefit from the funds available.

Because of the financial restraints faced by many jurisdictions, requests for appropriations for specific activities are coming under closer scrutiny. In competing for the necessary funds, signal maintenance officials will face a difficult task unless they can clearly document expenditures and the additional benefits that can accrue from increased appropriations.

APPENDIX A

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APPENDIX B

TYPICAL JOB DESCRIPTION FOR TRAFFIC SIGNAL MAINTENANCE

Traffic Signal Trainee Class Code 2038

Definition

Under immediate supervision, is responsible for learning to assemble, install, and repair electromechanical and electronic traffic signaling mechanisms; performs related duties as required.

Typical Tasks (illustrative only)

Learns to test and service signal master controllers; learns to repair and service traffic signaling equipment.

Learns to test circuits, tubes, and other components using various testing meters and devices; isolates defects and corrects or replaces defective parts.

Learns to adjust traffic signaling devices and equipment for the most efficient operation; learns how to perform preventive maintenance on traffic signaling equipment in the field.

Learns to prepare required reports and maintain necessary records.

Distinguishing Characteristics

This is a learner classification. Traffic Signal Technician is a "journeyman" or fully skilled level. Trades Helpers (Electrical) assist Traffic Signal Technicians and Linemen in their work. Persons appointed as Trainees may be employed in that capacity for a limited period not to exceed three years.

Employment Standards (at time of filing application)

Any combination of training and experience equivalent to completion of the eighth school grade and four years of experience in the electrical and/or electronic maintenance field; or two years as a Trades Helper (Electrical) in the Traffic Engineering and Parking Division of the City of ____________. Two years of formal classroom training in electricity or electronics may be substituted for two years of the required experience.

Possession of a valid State of Ohio motor vehicle operator's license.

Some knowledge of the basic principles of electricity and electronics; some knowledge of the techniques, tools, methods, and materials used in the lineman trade; some knowledge of the hazards and safety precautions of the trade; willingness and ability to climb poles and work at heights of 30 feet above ground; ability to develop and maintain effective working relationships with associates.

Class established 3-4-70
Current specs 2-10-71
Distributed 5-15-71

Traffic Signal Technician Class Code 3660

Definition

Under general supervision, is responsible for assembling, installing, and repairing electromechanical and electronic traffic signaling mechanisms; performs related tasks as required.

Typical Tasks (illustrative only)

Tests and services signal master controllers; repairs and services traffic signaling equipment.

Tests circuits, tubes, and other components using various testing meters and devices; isolates defects and corrects or replaces defective parts.

Adjusts traffic signaling devices and equipment for the most efficient operation; makes major field repairs and tests on traffic signaling equipment; does preventive maintenance in the field on traffic signaling equipment.

Assists traffic signal technician classes in assembling and installing, repairing and testing traffic signaling devices and signal control devices.

Prepares reports of work done.

Distinguishing Characteristics

This is the "journeyman" level of the series. A Traffic Signal Foreman I is a "leadman" or "straw boss." A Trades Helper (Electrical) assists technicians in the work.

Required General Experience and Training
(at time of filing application)

Completion of the eighth school grade and five years of experience in the electrical or electronic maintenance field, including two years as a Traffic Signal Trainee with the City of ____________ or comparable experience elsewhere. Substitutions: Two years of formal classroom training in electricity or electronics may be substituted for two years of the required general experience, but no substitution may be made for the Traffic Signal Trainee experience. No substitution may be made for the required education.

Possession of a valid State of Ohio motor vehicle operator's license.

Desirable Knowledge, Skills, and Abilities

General knowledge of tools, equipment, practices, and methods of installing, assembling, repairing, and maintaining electronic traffic signaling devices and accessory equipment; general knowledge of the construction and operation of traffic signaling devices and necessary equipment; ability to diagnose defects in traffic signaling equipment and to do skilled field work in the repair of electromechanical and electronic traffic signaling devices; ability to read blueprints, schematic drawings, and technical manuals; ability to maintain records and prepare reports.

Class established 4-8-63
Current spec 6-30-72
Distributed 8-15-72

Signal Maintenance Man

Definition

Under general supervision, to do semi-skilled and unskilled work in the installation, maintenance, and repair of traffic control devices; and to do related work as required.

Typical Tasks

Cleans, paints, and installs new gaskets in old traffic signal units; assists in making the simpler repairs to traffic signal units; installs new bulbs in traffic signals; erects poles and rigs span-wires to support traffic signals and radar units; drives a truck; maintains the signal shop in orderly condition.

Employment Standards

Any combination of education and experience equivalent to graduation from high school and one year of experience in the installation and maintenance of traffic control devices.

Knowledge of the materials, methods, and equipment used in the installation of traffic signals and their control devices; ability to follow oral and written instructions.

Senior Signal Technician

Definition

Under direction, to supervise and work with a small crew in the maintenance and repair of traffic and fire alarm signals and related systems and equipment; and to do related work as required.

Typical Tasks

Confers with supervisor on work programs and assigns, supervises, and checks work of subordinates; secures required supplies and equipment for jobs; does major testing and overhauling of equipment in shop; installs, repairs, and maintains electronic and electrical equipment and circuits in the field; maintains testing and repair equipment in good condition for use at all times; keeps traffic intersection plans and circuit diagrams on all equipment serviced; maintains job and personnel records.

Employment Standards

Any combination of education and experience equivalent to graduation from high school and three years of experience in traffic control and related equipment repair and maintenance.

Knowledge of the methods, materials, and equipment used in the maintenance and repair of electrical and electronic signal and control equipment; skill in testing, repairing, and overhauling such equipment; ability to interpret and work from wiring diagrams and technical manuals; ability to supervise and work with a small crew; ability to maintain records and prepare reports.

Traffic Control Superintendent

Definition

Under direction, to plan, coordinate, and supervise the installation and maintenance of traffic signs and markings, traffic signals, and parking meters; and to do related work as required.

Typical Tasks

Plans, organizes, schedules, directs, and coordinates the construction, installation, and maintenance of traffic signs and street markings, the installation and maintenance of traffic signals, and parking meter installation, repair, and collection; confers with traffic engineer relative to priorities and operating policies; inspects work in progress, reviews daily activity reports, and keeps the traffic engineer in-

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* Highway Research Board Special Report 80.

Rep. No.	*Title*
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formed of special problems and status of work; assists in design of signal installations; diagrams signal controls; conducts in-service training for personnel in technical aspects of signal operation, maintenance, construction, and sign painting; directs and advises subordinate employees in the construction and installation of new meter layouts, collection schedules, and maintenance of parking meter records; receives and investigates complaints and evaluates suggestions from the public; encourages safe working conditions and procedures; maintains records and prepares reports.

Employment Standards

Any combination of education and experience equivalent to graduation from high school and three years of experience in supervising construction, installation, and maintenance of traffic control signals and related devices.

Knowledge of materials, methods, and equipment used in installation, operation, and maintenance of traffic signals and of electronic and electromechanical traffic controllers and allied equipment; knowledge of fire alarm systems; knowledge of the principles and practices of traffic engineering as applied to the operation of traffic control devices; knowledge of street sign and marking methods, materials, and equipment; ability to interpret working diagrams and layouts of electronic equipment; ability to plan, lay out, and coordinate a work program; ability to analyze work operations and to prepare reports; ability to conduct in-service training of subordinates; ability to establish and maintain effective relationships with others.