NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
SYNTHESIS OF HIGHWAY PRACTICE 114

MANAGEMENT OF TRAFFIC SIGNAL MAINTENANCE

TRANSPORTATION RESEARCH BOARD
National Research Council

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MANAGEMENT OF TRAFFIC SIGNAL MAINTENANCE

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NATIONAL RESEARCH COUNCIL
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PREFACE

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

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

FOREWORD

By Staff
Transportation Research Board

This synthesis will be of interest to traffic engineers, maintenance engineers, and others responsible for managing the maintenance of traffic signal equipment and systems. Information is presented on the management aspects of signal maintenance including personnel, organization, costs, and controls.

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

Maintenance of traffic signal equipment and systems is a continuing and necessary function of highway agencies. This report of the Transportation Research Board discusses the management aspects of signal maintenance and contains information on types of maintenance, personnel needed, equipment and facilities required, organization, costs, and controls.

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

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

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Information on current practice was provided by many highway and transportation agencies. Their cooperation and assistance were most helpful.

MANAGEMENT OF TRAFFIC SIGNAL MAINTENANCE

SUMMARY

This publication is an update of *Synthesis of Highway Practice 22,* which was published in 1974. The update bears little resemblance to the original report because so much quantitative and descriptive material has become available in the past 10 years. Specific data are now available on the estimated costs and personnel requirements for intersections and systems of various complexities. Readers will find more information that will help them in formulating recommendations for staff additions, funds for equipment-replacement programs, and so forth.

The problem of inadequate maintenance is illustrated by a recent survey in Atlanta, which found that fully half of the signals were malfunctioning. Maintenance deficiencies that result in equipment malfunction are responsible for reduced equipment life, road-user costs of additional stops and delays, accidents, and increased energy consumption. Particular problem areas include nonstandardization of equipment, overuse of sophisticated control equipment and control schemes, and inadequate inspection during installation. There is a need to increase the capability of maintenance personnel to keep modern, sophisticated equipment in service. There are difficulties attributable to the use of low-grade components not suited to the environment, insufficient quality control, damage from power surges including lightning transients, and lack of funds for equipment-replacement programs. The types of signal maintenance include work done for preventive purposes (checking, adjusting, relamping, etc.) or work done in response to a trouble call (to restore normal operation). The failure to properly maintain a traffic signal could result in tort liability judgments against an agency. This risk can be managed and liability minimized through adherence to maintenance guidelines and procedures and adequate record keeping.

A transition in the requirements for maintenance personnel has taken place as hardware has evolved from electromechanical to solid-state design. Whereas electricians were needed to maintain older hardware, modern equipment requires skills in electronics. The newer control equipment has made traditional preventive maintenance procedures, such as adjusting and lubricating, even less cost-effective; however, group relamping remains cost-effective. An effective method of detecting malfunctions is periodic checking of signals for proper detector/controller operation. Each agency also needs to set priorities for responding to typical malfunctions.

Signal repair shops in agencies are used for acceptance testing and diagnosing malfunctions in addition to repairing equipment. For computer-based control systems, the shop may also be able to monitor the operation of controllers and detectors for malfunctions. A full complement of test equipment is needed in the shop and additional

equipment is needed in service vehicles; an inventory of spare parts is needed for both. The exact equipment and number of spares will depend on the type of signal equipment being used.

It is important to establish the responsibility for each individual element of the maintenance program. Signal maintenance preferably is located in the traffic unit but some agencies have had success with it located in a maintenance or electrical services unit. Another alternative is contract maintenance, either with another government agency (e.g., a city maintaining state signals) or with a private contractor or public utility.

Costs of maintenance will vary depending on type of equipment and detectors, stringency of purchase specifications, quality control during manufacturing and installation, environmental conditions, extent of malfunction detection capability, and other factors. Actual annual maintenance costs have been reported from a little over $100 per intersection to more than $1,600. However, these costs are quite small when compared to the costs to motorists of increased fuel use and delays caused by signals that are not properly maintained.

A number of management techniques are available to gain control over the multiple facets of the acquisition and maintenance of signals. Regarding technical control, the maintenance burden can be reduced by tightening procurement specifications and by following installation guidelines designed for the long run. Administrative control includes computer-assisted record keeping and determinations of mean time between failures and mean time to repair. These two measures have many uses, including computation of the number of spares that need to be stocked and the assigning of priorities for replacement of equipment that fails frequently.

Among the conclusions of this synthesis is that there is a need to reduce the mounting disparity between the control capability of modern, sophisticated equipment and the capability of the maintenance personnel. The gap needs to be closed in order that there be assurance that the maintenance personnel are in fact able to restore malfunctioning equipment promptly to safe and efficient performance. This goal needs to be met by efforts on two fronts: first, maintenance capabilities need to be upgraded through training programs for existing personnel, attraction and retention of appropriate personnel, and the use of contract maintenance; second, the maintainability of the controller/detector scheme needs to be improved by simplifying designs, enforcing standardization and interchangeability, and insisting on rigorous inspection and acceptance testing.

CHAPTER ONE

INTRODUCTION

Headlines from Washington tell a tale of woe familiar to the nation's traffic engineers, signal technicians, and traveling public: "D.C. STOPLIGHTS: HALT, LAME AND A PAIN TO MAINTAIN" (*1*). *The Washington Post* goes on to describe the District's old, electromechanical equipment as victims of old age, obsolescence, and deferred maintenance. It is a story of too few repairmen, too many makes and models to stock spares for, and too small a chance of being able to find replacement parts for equipment so old. The D.C. traffic engineers are planning a new system. "The trick will be persuading people to spend the money to keep it up," one of them says, "but I think the awareness is coming." Public awareness and political support must provide the foundation for the maintenance of traffic signals.

This report is a synthesis of available information, particularly published material, from the United States and abroad, on the management aspects of traffic-signal maintenance. It is an update of *NCHRP Synthesis of Highway Practice 22,* which was published in 1974 (*2*). Rather than a manual for the field troubleshooter or the repairman working at a bench in a signal shop, it is a report intended for use by management personnel responsible for staffing, budgeting, etc. Specific data are presented on the estimated costs and manpower requirements for intersections and systems of various complexities.

The introductory chapter shows the importance of proper maintenance and points out some particular problem areas. It goes on to define several types of maintenance. If maintenance is deficient then equipment malfunctions will produce adverse consequences such as additional stops and delay, more accidents, and so on, which are described. The chapter ends with an introduction to the elements of risk management, including the basics of legal responsibility and liability, and the consequences of failure to comply with maintenance standards or guidelines.

Subsequent chapters describe the maintenance effort, maintenance personnel, maintenance facilities and equipment, types of maintenance organizations, maintenance costs and funding, and administrative control.

A concluding chapter stresses the need to reduce equipment sophistication and enforce standardization. Other ways to reduce maintenance needs, or make required maintenance easier to perform, are to specify components with higher reliability and to demand modularity of components. Another conclusion is that routine, scheduled maintenance is no longer concerned primarily with preventive measures. Rather, the emphasis is on inspection patrols, and self-detection methods, to discover malfunctions and, on subsequent checking, to be certain that the faults have been corrected. A further conclusion is that the number of signalized intersections (including school flashers and flashing beacons) that can be maintained by one technician varies widely but seems typically to be in the range of 25 to 35. Maintenance contracts are cost-effective and practical in high-density areas, and are necessary for computers and much of the peripheral equipment.

The Bibliography lists documents that were not referenced in the report but may be of interest for further reading.

The appendixes are of unusual importance, furnishing details that the manager will find useful in setting staffing levels, hiring qualified personnel, stocking maintenance equipment and replacement parts, approaching the contracting of maintenance, keeping adequate records, testing competing brands of lamps, and specifying that maintenance training be furnished by equipment suppliers.

The appendixes do not include a glossary of terms because of ready availability elsewhere. Interested readers may wish to consult glossaries published by the International Municipal Signal Association (IMSA) (*3*), the Institute of Transportation Engineers (ITE) (*4*), and the Federal Highway Administration (FHWA) (*5*).

MAGNITUDE OF THE PROBLEM OF INADEQUATE MAINTENANCE

Signal deficiencies may conveniently be divided into "malfunctions" that produce a degradation of control level and "breakdowns" that cause a loss of signal indication. Evidence abounds from U.S. sources and those abroad that signal malfunctions and breakdowns are widespread and serious in their consequences. The problem lies not only in the frequency of failures but in excessive time before a failure may be reported.

In a recent field survey in Atlanta (*6*) 59 intersections were inspected by a three-man team from the city's traffic engineering staff. They found that nearly 50 percent of the intersections had equipment malfunctions that significantly restricted the smooth flow of traffic. In several cases the deficiency found was so severe that it rendered the signal totally inoperative.

Rowe reported in 1981 (*7*) that, in spite of a rigorous maintenance program, almost 24 percent of the signals in Los Angeles had malfunctions that would affect the efficiency of traffic flow.

In 1970, Cobbe and Ridley (*8*) described a British experience of the mid-1960s. Seventy signalized intersections in West London were checked on four separate occasions over a period of 18 months. On each occasion it was found that approximately 70 percent of the signals had faults that were serious enough to cause delay.

In 1977, Hulscher (*9*) reported the composition of the primary categories of traffic-signal malfunctions in Sydney, Australia.

The average signal had about 1.5 malfunction reports per month, broken down as follows:

Fault Category	Number per Month per Signal
Controller fault	0.40
Lamp burn-out	0.33
No fault found	0.20
Detector fault	0.19
Accident damage	0.14
Other fault	0.11
Pushbutton fault	0.09
System master fault	0.02
Total	1.48

CONSEQUENCES OF MAINTENANCE DEFICIENCIES

Maintenance deficiencies causing equipment malfunctions have serious impacts on equipment life, road-user costs of additional stops and delay, safety, fuel consumption, and pollutant emission.

Tillotson reported in 1975 (*10*) that a simple failure (such as a broken detector loop) can induce significant delay. By locking in a call to the controller, it will cause the green signal to extend to its maximum limit irrespective of traffic demands. If the signal is caused to operate as a fixed-time controller with a cycle length of the order of 120 seconds, then the extra delay amounts to about half the normal daily delay.

Faults in signal equipment in central London were estimated in 1970 to cause delays costing the community about £4,000 per year per intersection approach ($10,000 at that time) (*8*).

There are safety implications as well. Hulscher (*9*) inferred from New South Wales data that the overall accident rate at blacked-out or faulty signal locations is about eight times higher than a signal sites functioning normally.

A signal that is malfunctioning may be placed on flashing yellow/red by the maintenance crew or by a digital master that has recognized a problem. Nighttime data gathered at San Francisco (*11*) showed that accidents almost tripled when their signals were converted to flashing operation after midnight.

Rowe of the Los Angeles D.O.T. (*7*) used the TRANSYT computer program to estimate that hardware malfunctions increase the fuel consumption on surface streets by 0.5 percent. This amounts to 2.8 million extra gallons of gasoline per year and about a $3.6 million annual loss to Los Angeles drivers.

The cost-effectiveness of good maintenance is beyond question. Later herein it is shown that even if signal malfunctions were to increase stops and delay by just a small percentage and a second or two, respectively, the cost to motorists would far exceed the cost to maintain the signals properly.

PERCEIVED IMPORTANCE OF MAINTENANCE

In 1978 McGowan and Eicher (*12*) reported the results of a survey in which researchers, system designers, and manufacturers rated the relative importance of various traffic-control-system objectives. The survey showed that maintenance was clearly rated more important than any other aspect of the system. In this context, "maintenance" was defined as follows:

Maintainability
- Staff requirements
- Failure monitoring
- Field/office serviceability
- Degree of service disruption

Reliability
- Resistance to failure
- Provision of fallback control (to standby operation)

PARTICULAR PROBLEM AREAS

In 1982 the consulting firm of Edwards and Kelcey prepared guidelines for traffic-signal maintenance for the Pennsylvania D.O.T. (*13*). The firm's research and field trips to various municipalities identified three specific problem areas: nonstandardization of equipment, overuse of sophisticated control equipment and control scheme, and inadequate inspection during installation. Several other problem areas are also addressed in this section.

Nonstandardization of Equipment

Most agencies have in operation equipment purchased from a number of sources over a period of decades. (For example, almost 30 percent of the signal equipment in Atlanta is more than 25 years old and over 60 percent is more than 15 years old.) The wide variety of makes and models demands large inventories of replacement units and parts. Servicing is less efficient because of the difficulty of training personnel to maintain so many different designs.

Overuse of Sophisticated Control Equipment and Control Scheme

Later in this synthesis maintenance-cost data are presented showing that multiphase actuated controllers, with their detection loops and electronics units, are much more expensive to maintain than the electromechanical pretimed models. (The disparity is much less pronounced now that controllers and detector units are microprocessor-based.) Although sophisticated controller/detector configurations can effectively reduce delay to motorists, any advantage disappears if the equipment is not kept in good working order. If maintenance dollars and manpower are spread too thin, it may not be possible, for example, to keep all of the detectors in service. The only recourse is to set that controller phase to "recall," bringing the green to that approach at every opportunity, whether a vehicle is waiting or not. Over a period of time an expensive, sophisticated installation can be reduced to a pretimed operation offering little of the intent of the original design.

There is an increasing disparity between the control capability of modern, sophisticated equipment and the maintenance capability of the personnel assigned to keep it running. The day is approaching when a malfunctioning unit will be able to display a message to a relatively untrained troubleshooter to remove a certain board or card and replace it with another. Until that day arrives, and until the agencies have been able to upgrade their equipment to that level, there will be a pressing need to improve maintenance capability.

Tarnoff and Parsonson reported in 1981 (*14*) that the cost to maintain sophisticated control equipment and control schemes is more than justified by the resulting benefits to motorists. However, if an agency's budget simply does not allow adequate maintenance, then the designs should be simplified. It is better to plan for rudimentary actuated control, perhaps using magnetic detectors that are rugged and reliable, than to install multiple long loops that cannot be kept in service.

Inadequate Inspection during Installation

The report for the Pennsylvania D.O.T. (*13*) pointed out that maintenance problems often can be traced to installation errors that were not corrected because of inadequate inspection. Errors included violations of the National Electrical Code, improper installation of hardware, and incorrect operation of the equipment.

Many agencies do not use their own forces to install signals, preferring instead to award contracts to low bidders. In the absence of stringent prequalification procedures, the award can go to an electrical contractor with inadequate experience. If the inspection is also inadequate, the potential for errors and shortcutting is great. Examples include the breaking of insulation on wires caused by improper handling and the placement of signal heads on corner-located poles in such a way that they are brushed out of alignment by turning trucks. Many of these deficiencies may not show up during the period of the contractor's maintenance responsibility, and therefore must be corrected by the agency's own forces at a later date.

In all construction work, including signal installation, there is a need for much greater feedback from the inspectors to the designers and specification writers. Closed-loop communications in this area lead to improved signal plans and contracts.

Other Problem Areas

In addition to the maintenance problems pointed out by the Pennsylvania D.O.T., there are difficulties attributable to the use of low-grade components not suited to the environment, insufficient quality control, damage from power surges including lightning transients, and lack of funds for equipment-replacement programs.

TYPES OF MAINTENANCE

Several categories of maintenance have been adopted by various sources over the years. For example, Carlson (*15*) stated in 1976 that maintenance can fall into three basic categories: routine, which includes periodic checking, lubricating, and adjusting; preventive, including controller overhaul, relamping, cleaning, painting, and replacement of any damaged or defective parts; and emergency, to restore signal operation on an emergency basis. Maintenance or upgrading may also be done as a part of a reconstruction program, he noted.

The report prepared for the Pennsylvania D.O.T. (*13*) divided maintenance into three categories (preventive maintenance, response maintenance, and design modification), which are adopted as standard throughout the remainder of this synthesis.

Preventive Maintenance

Preventive maintenance is defined as the provision of periodic checks and procedures to ensure reliable operation of traffic signal equipment and reduce field failures.

Preventive maintenance can be implemented at two levels, A and B, where B is the minimum for reliable operation. For example, level A calls for painting the cabinet every 2 to 5 years, oiling hinges every year, replacing the filter once a year and cleaning it at mid-year. Level B omits the painting and oiling and services the filter only by replacing it once a year.

Response Maintenance

Response maintenance is the repair and return-to-normal-operation of failed equipment.

Response maintenance begins, for example, with a trip to an intersection within one hour to verify and identify a reported problem. This could be performed by the police or others. Then, the response by maintenance personnel can result in either *final repair* or *emergency repair.* Final repair involves repair or replacement of the failed equipment to restore the intersection to proper and safe operation in accordance with the state permit within 24 hours. This type of repair is required for span wires or signal heads knocked down as the result of an accident and for equipment failures involving lamp burnout, conflict monitor, flasher, load switch, or signal cable. For other types of failures, emergency repair is acceptable. Emergency repair temporarily restores safe operation within a 24-hour period. The repairs required to bring the equipment into conformance with the permit must then be completed within 30 days unless prohibited by weather conditions or availability of equipment.

The selection of time periods allowed to restore operation is difficult because of the liability implications. The PennDOT selections of time periods were based partly on the fact that in Pennsylvania much of the maintenance is performed by contractors who must travel quite a distance to the municipality.

Response maintenance can be implemented at three levels—A, B and C. Level C requires just a signal mechanic to provide complete service for electromechanical equipment only. Solid-state equipment can be serviced by the signal mechanic only by the swapping of units. Level B is performed by a signal technician, who is capable not only of level C work but also of troubleshooting systems and communications. A municipality desiring level A response capability would need to add a signal specialist able to perform bench repair of all equipment.

Design Modification

Design modification is defined as any change to the approved design and operation of a traffic signal that is justified because of a recurring problem. Usually it adds or removes a phase or a special function, or changes the signal display to correct a problem in a new installation.

RISK MANAGEMENT

Tort liability judgments related to inadequately maintained traffic signals cost government agencies large sums annually. The shield of sovereign immunity has eroded considerably, leading many agencies to develop appropriate methods to handle and monitor their exposure to loss. The logical process is known as risk management.

Basics of Legal Responsibility

Many articles and reports (such as Refs. *16–20*) have set forth the elements of negligence as applied to traffic-signal maintenance and have explained the liability of governmental agencies and their personnel. The International Municipal Signal Association ran a series of articles (including Refs. *21* and *22*) alerting the maintenance technicians to their vulnerability to suit. Another IMSA article, by Krueper (*18*), emphasized that potential liability can be reduced by keeping adequate maintenance records both in the office files and in the curbside cabinet.

Lawsuits in this area are based on allegations that negligence existed or that a hazard was a public nuisance. These lawsuits generally raise the following principal issues:

1. Did a potentially dangerous defect or hazard exist?
2. Was there injury or property damage?
3. What was the defendant's duty of care in this situation?
4. Was the defendant derelict in fulfilling that duty? For example, did this technician troubleshoot this controller in accordance with the standard of the reasonably prudent technician working in this part of the country and under these circumstances?
5. Did the damages or injuries result directly from the dereliction of duty?
6. Was the defendant aware of the hazard for some time before the accident? In that connection, was the presence of the defect phoned in by a motorist ("actual" notice), or would the agency have discovered the defect in the normal course of doing its work properly ("constructive" notice)?
7. Was there any contributory negligence (such as speeding) on the part of the plaintiff? In many states this can bar recovery by a plaintiff, whereas in others that have a "comparative negligence doctrine" the amount of the recovery would be reduced.
8. Could the defendant have warned the motorist of the hazard, or made the location safe by such means as police control, before correcting the hazard?
9. Was there reasonable time, method, and money to correct the hazard?

Failure to Comply with Maintenance Standards or Guidelines

A report by Thomas (*23*) discusses the legal implications of a highway department's failure to comply with design, safety, or maintenance guidelines. Cases are discussed that hold that guidelines applicable to maintenance and maintenance procedures may be admissible as evidence of the standard of care that the highway agency should have followed. A specified procedure may be put into evidence to establish that the department should have had notice of an unsafe condition and the department failed to meet its own standard of care.

Case Studies of the Failure to Maintain Traffic Signals

The ITE has published accounts of a number of lawsuits that demonstrate various aspects of improper signal maintenance (*24*).

The Louisiana case of *McDaniel v. Welsh* [234 So.2d 833 (La. 1970)] exemplifies the principle that improper maintenance or lack of maintenance, or the failure to make a timely response to malfunctions, are among the most common ways of incurring liability. At 11:30 a.m. on the day of the accident, the controller was replaced after complaints of flickering signals had been received. The exchange corrected the flickering and the technician departed without checking to see if the new controller operated correctly in other ways at this major intersection. A different malfunction was reported to the city police at about 5:00 p.m. on that same day. A policeman made a more-or-less cursory check, found no disorder, and did not notify the parish, which keeps members of the repair department on 24-hour call. By 9:00 p.m., when the accident occurred, the signals were all out and the intersection was so dark the signal heads themselves were not visible. The city police then called out the parish repair personnel, who found that the problem was of a type caused by faulty relays or loose connections. They then corrected the problem. The court found the parish negligent in not making a proper inspection and examination of the signal after the malfunction was reported at 5:00 p.m., not taking adequate measures to correct the defect, and allowing the malfunction to continue an unreasonable length of time (4 hours) following notice thereof. The report to the city police was considered by the court to be equivalent to notice to the parish because of an established arrangement for relaying trouble calls.

Another case indicates that an agency responsible for maintenance of a signal must use every means at its disposal to keep the signal maintained. In the case of *Croft v. Gulf and Western* [506 P.2d 541 (Ore. 1972)] the defendant signal manufacturer was dismissed from the case, leaving the Oregon State Highway Commission as sole defendant. On the morning of the accident it was raining and had been raining all night. After two cars collided at right-angles, the officer investigating the accident noticed that the traffic signals were showing green simultaneously for two conflicting directions. At the scene, both parties claimed to have had a green light. The officer then observed the signal for 45 minutes and noted 12 to 14 cycles during which the functioning was erratic. However, before he left the scene, the signals spontaneously commenced to function properly. Repair personnel arriving an hour after the accident found no moisture in the cabinet. As a precautionary measure, the technicians replaced a relay that was slightly discolored.

(The case description mentioned that frequent straightening of the signals was required because of high wind at the intersection, but there was no mention that the conflicting greens possibly could have been caused by poor splices or skinned insulation in the field wiring.)

The investigating officer had twice reported signal malfunctions at this intersection over the previous several months, but these malfunctions did not involve conflicting greens. Rather, the signals were out completely on one occasion, and stuck or hung in one indication in the other. However, on both occasions there was rain and dampness, prompting the officer to testify that every time it rained, or it got damp, the lights malfunctioned.

The case description did not discuss the variety of independent malfunctions that can accompany rain. The court specifically disagreed with the defendant's argument that there was no prior notice of the particular malfunction preceding the accident. The fact that two earlier malfunctions had occurred when it rained was sufficient notice, even though the complaints were completely different. Therefore, the court held that the defendant knew or should have known that the signal was malfunctioning before the accident.

During all three trouble calls, two of them before the accident, the technician changed a relay after making a visual inspection. He did not use his multitester to make any electrical checks. His supervisor gave additional testimony along the same line. The court concluded that the defendant had failed to properly repair the traffic signal after receiving these two complaints.

Suggestions for Reducing Risk

These two cases show that the maintenance manager should provide technicians with up-to-date equipment and should ensure that the equipment is being used. Mere visual inspections should not be allowed, nor should technicians be permitted to seek a "quick fix" by removing power and then reapplying it to restart (reinitialize) the controller. (This may allow a marginal semiconductor to cool enough to operate satisfactorily for a time, but the problem will reappear.) The manager should be sure that the maintenance technicians avoid "tunnel vision" that may cause them to repair only what they were sent out to repair. They should look for other problems that may exist and correct them.

Adequate maintenance records should be kept so that in the event of litigation there will be no doubt as to what was done and when. The following items should be included in a maintenance record:

1. Identification of the person who made the complaint.
2. The time the complaint was received by the dispatcher.
3. The time it was given to the repair crew.
4. The time the crew responded.
5. The time the repair was completed.
6. The trouble that was found, including that found by the maintenance person.
7. The repairs that were made.
8. The materials that were used.

Appendix C includes examples of several forms suitable for keeping these records.

Further suggestions for reducing risk can be found in *NCHRP Synthesis 106: Practical Guidelines for Minimizing Tort Liability* (*25*).

CHAPTER TWO

DESCRIPTION OF THE MAINTENANCE EFFORT

Over the past 20 years there has been an evolution—perhaps a revolution—of control-equipment design. The emphasis in maintenance has shifted away from tasks that can be performed by an electrician and a signal "mechanic" toward those requiring highly developed skills in electronics. Every jurisdiction has alternatives in the selection of the signal equipment it will purchase. Each alternative has its own requirements for personnel for operation and maintenance. Some alternatives may demand complex maintenance tasks that are beyond the capability of the jurisdiction's present staff. If the community believes that personnel with these skills cannot be attracted and retained, and if contract services are not available, then it will be necessary to eliminate from consideration those alternatives that cannot be maintained. The need is for each jurisdiction to select only that equipment it is in a position to maintain. Stated another way, judicious equipment selection will mold the maintenance tasks to what is feasible for that organization.

These days, because of advances in technology, traffic-signal equipment is becoming so sophisticated that it is easily suited to the unsophisticated user. Self-diagnostic capabilities of new equipment indicate that we are nearing the day when the malfunctioning controller itself will display a message to the repair person to throw away a certain board or card and replace it with another. When this day comes, the selection of timing and the checking of operation of the intersection will be more challenging than the correction of malfunctions.

IS PREVENTIVE MAINTENANCE WORTHWHILE?

Inasmuch as solid-state equipment has no moving parts, the need for preventive maintenance of modern equipment is much less than it was when controllers were electromechanical. Even when equipment has moving parts, it is not at all clear that preventive maintenance (lubricating, cleaning, and adjusting) is effective. However, a locality that has found its preventive maintenance program to be cost-effective ought to continue to perform this work.

Scheck (*26*) reported a study of traffic-signal diagnostic equipment and preventive maintenance procedures. He analyzed maintenance data provided by the Ohio D.O.T. and found that all types of components failed after random lengths of time. None of them, not even the electromechanical relays and controllers, showed failure patterns that suggested wearing out with time. (The only exception, of course, was lamps.) He concluded that there is no justification for a preventive-maintenance program for controllers and components, even electromechanical units.

Scheck pointed out that this conclusion is supported by data from the New York State D.O.T., which has the responsibility for signal maintenance in a number of highway districts throughout the state. In 1976 the NYSDOT performed a study of the impact of the preventive maintenance effort (*27*). An on-site investigation of randomly selected signals in Regions 1 and 2 was made. Region 1 had a minimal preventive maintenance (PM) effort and Region 2 had a maximum program. In each region 25 signals were selected to give a representative mix of two-phase semi-actuated, two-phase full-actuated, two-phase pretimed, and flashing signals. There were no multiphase controllers in the random samples. An inspection team assessed penalties for actuated phases operating on recall and for PM-related deficiencies, such as dirty lenses, improper face aiming, rusty poles, inoperative auxiliary equipment, and timing settings not responsive to traffic flow patterns. The mean score for Region 2 was about 8 percent higher than that for Region 1. Statistical tests accounting for the dispersions of the 25 scores about their means showed that it was not possible to state with 95 percent confidence that Region 2 signals were operating better than those in Region 1, despite the pronounced differences in their PM programs. The NYSDOT concluded that preventive maintenance is not worthwhile, especially with the newer, solid-state controllers. As of 1984 the NYSDOT had not performed any preventive maintenance for several years and had not noticed an increase in PM-preventable failures (*28*).

Parsonson and Tarnoff (*29*) reported data from a substantial number of electromechanical pretimed and semi-actuated controllers in Cincinnati showing that the units over 20 years of age required no more service calls per year than did the newer models. In Tampa these same types of controllers exhibited failure rates for the units over 20 years of age that were comparable to the rates for models that were approximately 10 years old. These results tend to reinforce Scheck's findings that electromechanical parts fail after random lengths of time.

Scheck also discovered that some "infant mortality" may be an illusion created by certain maintenance practices.

> One would expect electro-mechanical relays to show few failures early in their lives. The frequency of failures should increase as wear causes malfunctions. The frequency should peak with a few units having a very long life. The data shows the opposite effect. Early-life failures are more common than late failures.
>
> These results may be explained in part by maintenance practices. If a technician is not sure of the cause of a malfunction, he may replace a component. A few days later the same signal may again be reported as malfunctioning. If the symptoms are the same, he may replace the same component. This routine may be followed for several repair calls until the cause is correctly identified. Meanwhile the maintenance record will show several failures of the same component over a short period of time (*26*).

Experience in London led Cobbe and Ridley to the same conclusion; i.e., that preventive maintenance is not effective.

> Again, regardless of [whether maintenance is contracted out or not] the question of preventive maintenance by routine inspection should be critically examined. From the high fault incidence rate there is little to suggest that preventive maintenance [performed quarterly], except for lamp replacement, is contributing greatly. . . . Since the rewards to be gained by ensuring satisfactory reporting, remedial work and inspection are likely to be far greater it is a reasonable decision that preventive maintenance should be omitted. . . . The function of inspection [ought rather to be] the discovery of faults and the subsequent checking that the faults have been corrected, the latter duty being particularly important (*8*).

On the other hand, in the event of a lawsuit over an accident allegedly caused by a controller failure, the court will usually hold that the agency had a "duty to care" to perform whatever preventive maintenance is recommended by the manufacturer. For example, the manual for a widely used electromechanical pretimed controller calls for a preventive-maintenance *inspection* once a year (*30*). Although no part of this controller requires lubrication, and no routine cleaning of the contacts is recommended, there are various gaps and tolerances that are recommended to be checked, and all screws should be tightened. The manual of a competing electromechanical pretimed controller calls for no lubrication ever, under normal atmospheric conditions, and adjustments are recommended only after certain parts are removed and replaced. No periodic inspections are called for (*31*). These two manuals reinforce the concept that the emphasis in "preventive" maintenance is not primarily on lubricating, cleaning and adjusting but rather on checking the detector/controller configuration for failures.

DETAILED TASKS FOR PREVENTIVE MAINTENANCE

Farrell stated that "preventive maintenance is a subject discussed often but performed very little" (*32*). Of the many sources of checklists of tasks (including *3, 33,* and *34*), the report for PennDOT (*13*) is especially thorough and detailed in this regard. That report considers that preventive maintenance can be implemented at two levels, A and B, where B is the minimum for reliable operation. The tasks are broken into mechanical and electrical types.

Preventive Mechanical Maintenance in Field

The report for PennDOT has set forth in detail the specific tasks required at the A and B levels, and at various time intervals, to provide the needed "mechanical" maintenance on the cabinet, signal heads, mast arms, span wires, poles, pushbuttons, detector sensors, and underground junction boxes and handholes. Each task includes an estimate of the time required (e.g., 10 minutes to clean the lenses, signs, and reflectors of a signal face and 2 minutes to replace the lamps). These times are translated into manpower requirements in a later chapter on maintenance costs and funding. See Appendix A for the complete list of tasks at both A and B levels, including time estimates. The report for PennDOT (*13*) includes a discussion of each item, such as the procedure for using a test lamp to check the adequacy of the ground rod.

Experience with Aluminum and Polycarbonate Heads

In 1971 Chamberlain (*35*) reported that a polycarbonate resin plastic named Lexan had been found to be suitable for the fabrication of signal heads and lenses. The signal body is less than half the weight of a die-cast aluminum head, and the built-in color eliminates costly repainting. It is resistant to the moist, salty air found along seacoasts.

Because of their light weight, polycarbonate signals may require tether cables to keep them from blowing around excessively in the wind. Also, certain lamps may burn polycarbonate lenses, particularly at locations where the signal goes for long periods without changing. In addition, a survey by Souder in 1982 (*36*) revealed that some use-failures (as opposed to collisions) were occurring near where the head is mounted on its support. These fatigue failures are caused by wind loads and can easily be eliminated by the use of an aluminum adapter, Souder reported.

Group Relamping Programs

Replacement of individual lamp burnouts is an expensive approach to relamping, therefore most jurisdictions minimize this task by group replacement of lamps at regularly scheduled intervals. The frequency with which relamping is performed should be dictated not only by bulb-life statistics but also by the required frequency of those services that should be performed at the same time as lamp replacement. These services include washing the lenses, polishing the reflectors, carefully positioning each lamp, and keeping records of the services performed. The frequency of the cleaning is important, as a survey in seven major cities showed that soil on the lenses and reflectors was causing a loss of 45 percent of the illumination (*37*). The author of that article estimated that burnouts can be reduced to 2 or 3 percent per year by using 8,000- or 9,000-hour-rated lamps on a one-year group replacement cycle. In the absence of any group relamping program, outage is likely to run from 20 to 40 percent per year depending on the rated life of lamps used and the degree to which the line voltage delivered by the power company matches the rated voltage of the lamp (*37*).

In Los Angeles, signal relamp and cleaning is performed on a yearly cycle by three one-man crews. Only 7 percent of all signal lamps are replaced by emergency crews.

Tindale, in 1976, described the steps leading to a decision to adopt a group relamping program in Tampa, Florida (*38*). Each year Tampa was replacing about 22 percent of its lamps at burnout, and this effort made up about 30 percent of the total work orders. A particular worry was that between 1971 and 1974 lamp burnouts increased 55 percent, and the cost of labor and fuel for emergency replacement rose by over 108 percent. Inasmuch as Tampa planned to upgrade its signals by adding a significant number of lamps, it was clear that a scheduled lamp-replacement program was needed. Tindale made a comparison, reproduced here in its entirety, of the comparative costs of replacing lamps on a burnout basis and on a scheduled basis:

> To determine the cost of replacing bulbs on a burn-out basis, the following analysis was made:
>
> 1. A statistical sample of our maintenance calls involving the replacement of burned-out bulbs was taken. From this sample, an average per call traveled distance and time consumed was computed. The former was computed to be 10.03 miles, the latter 36.08 minutes.
> 2. A unit fuel and vehicle operating cost was determined. The former computed to be \$.076/mile traveled, the latter \$.15/mile traveled.
> 3. An average hourly labor cost (excluding overhead and fringe costs) was computed, averaging the salaries of employees used to replace lamps, at \$4.02/hour.
> 4. A unit lamp price was calculated, based on the percentage of various lamps in use in the field and their respective present purchase price, at \$.38/lamp.
> 5. A total price per bulb change was calculated: labor (\$/minute) × (average time taken) + fuel cost (\$/mile) × (miles traveled) + vehicle operating cost (\$/mile) × (miles traveled) + lamp cost = \$/lamp replaced.
>
> Total unit cost/lamp changed: labor (.067) × (36.08) + fuel (.076) × (10.03) + vehicle operating (.15) × (10.03) + lamps (.38) = \$5.07 per lamp replaced.
>
> 6. A total yearly emergency lamp replacement cost was then computed (cost/lamp changed) × (estimated total lamps changed/year) = total cost/year:
>
> (\$5.07) × (1,908) = \$9,673.56/year
>
> With the proper statistical methods used and appropriate unit cost determined for all identifiable variables affecting the cost, any municipality can develop a realistic estimate of the cost of its present lamp program.
>
> To determine the estimated cost of a scheduled lamp program, the following analysis was used.
>
> 1. Two persons could change all the bulbs at an intersection in one hour or, in an eight-hour workday, two persons could change all lamps at eight intersections.
> 2. The average travel distance round trip would be 13 miles.
> 3. Approximately 8,500 lamps were in the field.
> 4. There are approximately 400 signalized locations.
> 5. The two technicians working in the program would be paid \$3.94/hour.
> 6. The average cost of a lamp is \$.38.
> 7. Vehicle operating plus fuel cost is estimated to be \$.226/mile.
>
> With the above information and assumptions, the following calculations were made:
>
> 1. Average lamps per intersection:
>
> $$\frac{8{,}500}{400} = 21.25 \text{ lamps/intersection}$$
>
> 2. Lamps changed per eight hours:
>
> $$\frac{\text{eight intersections}}{\text{eight hours}} \times 21.5 \text{ lamps/intersection} = 172 \text{ lamps/8 hours}$$
>
> 3. Labor cost per bulb:
>
> $$\frac{8 \text{ hours}}{172 \text{ lamps}} \times \frac{\$7.88}{\text{hour}} = \$.33/\text{bulb}$$
>
> 4. Fuel and vehicle cost:
>
> $$\$.226/\text{mile} \times 13 \text{ miles/day} \div \frac{172 \text{ lamp}}{\text{day}} = \$.016/\text{lamp}.$$
>
> 5. The estimated unit lamp replacement cost under a scheduled basis is:
>
> labor + vehicle operation + lamp
> .33 + .016 + .38 = .73
>
> 6. Estimated total lamp replacement cost:
>
> \$.73/lamp (8,500 lamps) = \$6,205.
>
> 7. Yearly scheduled lamp replacement cost assuming an 18-month replacement cycle:
>
> \$6,205/year ÷ 1.5 years = \$4,136/year.
>
> From these calculations, it was estimated that the yearly savings was \$9,673 − \$4,136 = \$5,537.
>
> With the more effective results to the public—fewer burnouts displayed, more lumens output due to cleaner lenses and the available tower truck and equipment during the evening shifts—a lamp program became acceptable to the policy makers (*38*).

After implementation of the scheduled-replacement program, Tindale found that an average of only 131 lamps (not the assumed 172) could be changed in an 8-hour shift. Also, the calculations omitted the fact that there would still be some replacement of burnouts (38/month compared to 159/month before). These two corrections reduced the yearly savings from $5,537 to $2,361. However, the increase in brightness of the signals—owing to the clean lenses and reflectors and the new lamps—is very noticeable. Moreover, the lamp program has reduced the required emergency overhead work, introducing the opportunity to use small, inexpensive vans for most of the maintenance work (*38*).

Tindale analyzed the claims of lamp manufacturers and arrived at the following proposed guidelines for lamp purchase:

1. Specify correct light center length.
2. Specify number of lumens per watt consumed at a rated voltage of 117. (The present use is 13 lumen/watt @ 117 volts.)
3. Specify rated life of the bulb.
4. Be aware of the depreciation rate of the lumens output and purchase bulbs in which good documentation shows a slow depreciation of lumens output.
5. Contact your State Department of Transportation if you are not confident of the claims of a manufacturer. You may also have the lamps tested by one of the large lamp manufacturers (the latter was done with success in Tampa) (*38*).

Test programs have shown significant differences among brands claiming a life of 8,000 hours. By purchasing lamps that test well, Delaware has been able to extend their relamping period to three years. The details of the Delaware test procedure are presented herein as Appendix G.

The North Carolina D.O.T. purchases lamps rated at 130 volts rather than the usual 122 volts. When powered with the normal 120 volts, the 130-volt lamps last approximately 20,000 hours, which is two and a half times the rated life of the lamp. The loss in light output amounts to 12 to 14 percent, which is not enough to be discernible to their traffic engineers when tested with red lenses under field conditions. Energy costs are reduced about 5 percent. The N.C.D.O.T. has estimated that it costs an average of $75 to dispatch a technician to change a 90-cent lamp, so they are pleased with their use of the 130-volt models.

Preventive Electrical Maintenance in the Field

Just as the PennDOT report (*13*) details preventive mechanical field maintenance, it also thoroughly describes the electrical maintenance for electromechanical and solid-state control equipment. Appendix B includes a list of these tasks. Maintenance intervals in months and task times in minutes are set forth for dial assemblies, cam assemblies, relays, flashers, switches, terminal connections, timing-setting checks, detector units, load switches, conflict monitor, and interconnect equipment. Just as for mechanical maintenance, these tasks are later converted to manpower needs (see Chapter 6).

The check of timing settings can be performed by a signal mechanic if all that is desired is a comparison of the settings posted inside the cabinet with those plainly set on the equipment by means of keys, dials, thumbwheel switches, or timing pins. If a keyboard-entry microprocessor controller or coordination unit is to be checked, or if it is desired to check the adequacy and appropriateness of the timing, then a higher level of training may be needed.

Preventive maintenance of interconnect equipment includes the following tasks in the PennDOT report (*13*):

- Controller Operation: The controller shall be checked to confirm it to be functioning in the mode selected by the supervisory master and local mode switches.
- Check for Free or Backup Operation: The input to the interconnect equipment shall be disconnected to check if the intersection control returns to the backup mode. Defective equipment shall be repaired or replaced and the input reconnected.
- Check special equipment: All tests recommended by the manufacturer shall be performed at the specified intervals. In all cases the equipment shall function properly when the inspection is completed.

This example of the details of a task makes it clear that the emphasis in "preventive" maintenance is to check to see that all equipment is functioning properly and to take positive steps to repair or replace defective equipment. The use of patrols to detect malfunctions is discussed later in this chapter.

Communications Equipment

The systems maintenance crew is responsible for resolving problems in the field involving adaptors, communication units, standby interconnects, and preemption systems.

Maintenance aspects of cable and conduit, multiplexing equipment, and leased telephone lines are discussed in *Synthesis 22* (*2*) and in the *Traffic Control Systems Handbook* (*5*).

In 1980, Cimento (*39*) discussed maintenance aspects of hardware used in digital traffic control systems. He explained the reliability, maintainability, damage resistance, and monitoring capability (for failures) of the various subsystems of controllers, detectors, and so on. He concluded that communications are the single biggest problem. The newer technologies (e.g., time-division multiplexing, digital circuitry, microprocessors) are the most susceptible to operating problems (line disturbances, ambient noise, lightning) and are the most difficult to troubleshoot. His findings are presented in detail herein in Chapter 7.

Cables and Conduit

Underground installations of cable and conduit are very difficult to inspect because of their inaccessibility. Normally, underground cable can be inspected visually only where it is exposed, such as in handholes or pull boxes. Electrical tests, such as a determination of resistance to ground, aid in troubleshooting. Spare conductors, if present, can be used to replace damaged ones (*2*).

Fall-Back Capabilities at the Intersection

The maintenance of communications at the local intersection currently is aided by a number of design features, such as redundant circuits and fall-back to time-based coordination.

Multiplexing Equipment

The FHWA (*5*) notes that electronic multiplexing equipment is unfamiliar to most signal technicians. They need specialized training and sophisticated test equipment to acquire the necessary maintenance proficiency on these items.

Ficklin (*40*) described a problem in which over one-fourth of the field communication units failed during the warranty period. The manufacturer took two months or more to repair and return a failed unit, so that "typically, 20 or more intersections were offline at any given time during most of the warranty period, resulting in poor traffic coordination and much negative public and media reaction." The situation was not resolved until more spares were purchased and the expiration of the warranty period made it unnecessary to return failed units to the factory.

Overland Park, Kansas, implemented a communications system that shared space on a commercial cable TV network (*41*). Serious communications problems plagued the system from the first day until they were all eventually corrected a year and a half later. The problems were traced to two major areas: noise on the cable and improper set-up of the modems. The noise problems were alleviated by tightening all connections and installing special filters. The set-up procedures for the modems were adjusted to be suitable for use outdoors on a cable shared with TV.

Leased Telephone Lines

As part of the lease arrangement, the telephone company normally provides the required maintenance.

Master Control Equipment

Modern digital systems include master control equipment that may be located curbside ("on-street") or at central locations, such as city hall and the signal shop. Both the hardware and software must be maintained. Bigelow (*42*) has published a checklist of items that the data processing manager and legal council should consider from a contractual point of view when installing or expanding the system. It addresses both hardware and software.

Hardware Maintenance

Until recently it has been a universal practice to contract out the maintenance of the computers and peripheral devices. Currently, some manufacturers offer mail-in service for boards removed from their personal computers and desk-top models. Contracts are made with the computer manufacturer or a service subsidiary or with an independent service firm with close ties to the manufacturer. Usually the contract provides for both preventive and response maintenance, including parts and labor, for a fixed monthly fee. The FHWA adds:

> Other decisions must be made concerning response time and down time. Even though satisfactorily used by some smaller systems, contracts which permit a next business day response would generally be unacceptable for a real-time traffic control system. Such a contract provision would be critical if a breakdown occurred, for example, at the beginning of a holiday weekend. Further, a maintenance agreement which would permit the computer to be taken off line for routine or preventive service during a peak traffic period would be unacceptable. These selected illustrations merely emphasize that it is essential to match the provisions of any maintenance agreement with the desired system performance level (*5*).

One solution to the problem of response time and down time is to purchase two of everything—two computers, two disk drives, and so on. Atlanta, for example, uses its second computer for off-line tasks, normally, but it is ready to take over real-time traffic control if the first computer fails or is taken off line for maintenance.

Maintenance of central communications modules and the map display usually is performed by the operating agency. The use of systems managers for this purpose is discussed in Chapter 5.

Cimento (*39*) noted that computerized systems require a reasonable commitment in maintenance and operating support. This includes adequate spares and an equipment servicing routine. Good record-keeping procedures are more important now, he adds, for systematic troubleshooting and effective system upkeep.

Tarnoff (*43*) reported the results of a group discussion aimed at identifying features of simpler, lower-cost traffic-control systems for smaller communities. It was agreed that a user-friendly system would have the following maintenance characteristics:

- Self-diagnostic capability including system exercisers to support diagnosis.
- Ease of component changeout including fewer boards, increased use of plugs.
- Elimination of preventive maintenance activities.
- Elimination of special environmental and power requirements.
- Availability of self-training courses.
- Use of standardized documentation symbols.

Software Maintenance

The computer programs are usually provided at the time of system installation as a complete, operating, tested, and debugged package. However, complex programs will reveal additional flaws, or bugs, during their first few years of operation because of the multitude of different computational combinations of circumstances that will arise over time. Software "maintenance" is the altering of the program to fix each bug as it develops. Other maintenance tasks are described by the FHWA (*5*) to be required when:

- The configuration of the computer-controlled system changes.
- Additional control algorithms, timing plans, and data-processing routines are developed and tested.
- Different statistical reports on system performance are required.

This will require the services of a programmer highly proficient in real-time systems and in the specific software used in the system. *Synthesis 22* (*2*) noted that it is customary for the original software firm to furnish software maintenance for a period of typically one year. After that period the operating agency must make a decision as to how this programming capability will be provided; by in-house personnel, by contract with the original vendor, or by a software consultant. However, software maintenance by other than the original supplier could only be accomplished if all of the following conditions are met:

1. The original program is very well documented.
2. It is also well designed and in modules.
3. The new programmer is highly proficient in the language and the computer used in the system.

Changes in system configuration and the addition of control algorithms can be accomplished via the operator's interface in most newer systems, without software changes. The computer can usually be programmed to provide different or additional statistical reports on system performance by someone reasonably proficient in programming.

Software maintenance requires detailed documentation, including logic flowcharts, program listings with explanatory comments, and a user's manual (*5*).

DETECTION OF MALFUNCTIONS

Faults in signal operation are discovered and reported in a number of ways. Many agencies carry out routine inspections periodically, and in recent years computer-based detection of malfunctions has increased in use. Complaints by the public to the police and the traffic engineering department remain primary means of detection.

Based on London experience around 1970, Cobbe and Ridley (*8*) believed that the main problem of signal maintenance may well be not the "mean time between failures" but the "excessive time before reporting."

Patrols

Cobbe and Ridley (*8*) also believe that preventive maintenance should be omitted. The function of inspection, then, would be to discover faults and to perform the follow-up checks to ensure that the remedial work is done properly.

Periodically, Atlanta conducts a Maintenance Day, on which six two-man teams of skilled engineers and technicians are dispatched to all areas of the city to check traffic signals, street lights, signs, and markings. Several hundred job orders are generated and are prioritized for the attention of the work crews.

In Los Angeles, when the emergency one-man signal-maintenance crews are not responding to trouble calls, they are assigned to a routine signal-inspection program. One complete cycle of the routine inspection program is completed every 45 days (*44*). Rowe goes on to explain:

> A far more extensive inspection and preventive maintenance program is carried out by four two-man crews on an 18-month cycle. This program covers inspection of the controller, signal heads and standards, and pull boxes. All interconnected systems are inspected separately for proper operation of communications equipment by six one-man crews. Master controllers are checked on a weekly basis and local controllers on a 60-day cycle. Field maintenance work which is too extensive to be accomplished during routine inspections is handled by special two-man "work order" crews (*44*).

Public Complaints

Educational programs seem to be needed to make the public more aware of their role in reporting malfunctions. Assistance from the news media is needed to enlist public participation. Other aids to reporting by the public include lectures in driver training programs, and an easy reporting procedure that is widely publicized. The cooperation of fleet operators is particularly desirable (*2*); transit buses in Atlanta are equipped with two-way radios, enabling the drivers to call in malfunctions.

Self-detection

Computerized traffic control systems may automatically detect serious malfunctions long before a complaint is received from the public. The computer can institute degraded operation, such as pretimed, recall of a phase, flashing, or isolated control. Computer control also enables remote diagnosis and confirmation of malfunction reports by citizens, police, etc. before dispatching a repair crew.

London Experience

As of 1979 about half of the 2,000 signalized intersections in the Greater London area were directly controlled by two computers (*45*). Failures are categorized either as an "alarm" or as a "warning" by the computer. An "alarm" is a serious malfunction of equipment, such as signal stuck, wrong phase indication, data corruption, communication-line failure, or four other categories. In these cases the intersection is dropped from control and allowed to function as an isolated site; however, a monitoring facility is retained, which often permits diagnosis as to whether the fault is located in the basic signal equipment or in the computer control devices. It is normal to drop all intersections in that control section when one intersection enters the "alarm" state, thereby allowing a local master control (if present) to take over the coordination within that section.

A "warning" is a less serious signal condition that does not justify termination of either computer control or local-controller operation. Typical warnings are intermittent data-transmission errors, minor timing faults, and nine other categories.

The real-time software in the Greater London system includes a number of available commands aimed primarily at fault diagnosis and maintenance.

> These include the ability to drop individual [intersections] from computer control, and if necessary prevent them from being taken over by the computer automatically if a malfunction persists. [Intersections] may be monitored while test equipment is connected by a technician at the street location; in this case the operator [at central] is able to verify the effectiveness of any remedial action taken on site to cure a fault (*45*).

U.S. Experience Since the 1970s

The *Traffic Control Systems Handbook* (*5*) summarizes the practices since the 1970s in performing continuous, automatic testing of system components for failures or substandard performance. The components monitored include detectors, local controllers, variable-message signs, computer system, and communications system.

A failure of a detector electronics unit, or of the detector-communications electronics, is indicated if a call persists too long (e.g., over 12 minutes), or has been absent for too long, or is producing a count higher or lower than historically has been observed at that location at that time of day. Some detector electronics units have a remote reset feature that allows the central computer to attempt to clear a persistent actuation and restore normal operation without a trouble call to the site by maintenance personnel.

A local controller sends back to the central computer information on how it is cycling through its prescribed intervals. Often only main-street green is monitored, but additional intervals can be communicated back for a more positive check on what the controller is doing. If the computer determines that the controller has stopped cycling, or in some other way is not responding to computer commands to go to a certain interval, it reports that the controller has failed and alerts maintenance personnel.

The sign-control unit (SCU) in a variable-message sign stores the message received from the computer. If the SCU is unable to correctly echo the intended message, then an SCU failure is indicated. Each sign is continuously monitored by its SCU, which immediately reports failures to the computer. Power failures affecting the entire sign or individual components are reported, and battery backup continues to operate the sign until power is restored (*5*).

The computer's program includes a set of diagnostic routines that seek out malfunctions in the following components of the computer system (*5*): the computer memory, the internal instruction performance, the digital traffic input-output interface, the interrupt system, and the peripheral equipment.

Communications are monitored for errors by means of a parity-check scheme. When a transmission error is detected in a message, the receiver requests a retransmission of the message (*5*).

Current Advances in Self-detection

The malfunction diagnostics just described were implemented in the larger central-computer systems in the 1970s. Currently, the same concepts are being extended to systems with on-street remote-master controllers. Known as "closed-loop systems," the on-street master detects and identifies errors or malfunctions and transmits reports back to a manned central office (*46*). An installation turned on in early 1984 in Atlanta has a master that continually monitors sampling sensor data for proper operation. Each sensor is checked for constant calls, absence of calls, and erratic outputs. A failed detector is automatically deleted from volume and occupancy calculations, but is restored if proper operation resumes. A designated number of sensors on each computational channel must operate properly for the master to remain in the traffic responsive mode. Otherwise, the system is automatically placed in the backup time-of-day mode.

Another important function of the master is to receive failure and status messages from the local intersections. These messages, along with the time and place of their occurrence, are always stored in the master for up to 48 hours. Any event may also be programmed for immediate report to the central office upon occurrence. The entire log of messages for the last 24-hour period can be requested for printout at the central office on demand, or programmed for automatic transmission at a specific time.

At each intersection there is a unit Atlanta calls a local system supervisor (LSS). It interfaces with a NEMA (National Electrical Manufacturers Association) actuated controller. Timing patterns are implemented by commands from the LSS to the controller to "hold" and "force off." The LSS also performs numerous supervisory functions by continually monitoring the operation of the local controller, the conflict monitor, and other selected cabinet functions. Appropriate fault messages are immediately transmitted to the central office computer when improper operation is detected.

For instance, the LSS continually monitors the local controller operation to ensure that the controller is in step with master commands and is responding properly to side-street calls. If the controller does not stay in step with the master, it is automatically disconnected from system control and placed in "free" operation. If the controller hangs up, the intersection is placed in flashing operation.

The LSS also monitors other aspects of the local cabinet operation. Six inputs are provided on the unit to monitor virtually any cabinet condition. These inputs are normally used to monitor such functions as conflict flash, manual flash, time clock flash, pre-emption active, and manual control active.

The LSS transmits a message to the master when the initial failure or monitored condition begins, and also another message when normal operation resumes. Any monitoring channel can be programmed to report a failure immediately to the central office, or the messages can be stored at the master for summary printout at the end of the day.

At the central-office facility, the operator has the option of having automatic failure or status messages dislayed on the CRT only or printed. Messages designate the intersection name, the mode of failure or status, and the time of occurrence. "Resumed normal" messages include the same information.

Some digital systems are designed so that the manufacturer, at the factory or main office, can diagnose malfunctions in any of the systems sold to recommend appropriate corrective action. The key to this capability is for all of a manufacturer's systems to have a standardized master that includes a dial-up function for the diagnostics. The manufacturer maintains a disc file on all systems and always has at least one master in-house. The remote dial-up function allows the manufacturer to connect with any of the masters world-wide. By long-distance telephone the manufacturer can go through any master to the intersections and bring back and display all timings from the locals, as well as the current operational plan utilized by the master. The manufacturer can also display on the remote CRT as well as the local CRT, UART[1] errors, log of disc errors, and on-line

[1] Universal Asynchronous Receiver and Transmitter (UART) is a chip that handles transmission and reception in a communications modem.

parity checks. The customer service department can dial up a master, put the designated disc pack in service on the in-house master, and duplicate the remote master's operation. This department can determine a hardware, software, or operational error. The success of this operation is attributable to the standardized master for all systems sold by a particular manufacturer.

RESPONSE PROCEDURE

The management of the response procedure includes the provision of a dispatching routine, the setting of response priorities, the assurance of adequate off-hours emergency response, and the enforcement of written policies and procedures for the actual repair. Areas of particular emphasis are the keeping of good records and the follow-up to ensure the quality of the work.

Dispatching

Synthesis 22 noted that a jurisdiction that does its own signal-installation work may wish to instruct its dispatcher to make an effort to see that all maintenance and repair work is done by the installing personnel (*2*).

The dispatching procedure tends to be more formal in those arrangements where maintenance is performed by a separate governmental agency, or by a public utility or by a private maintenance contractor. More than one agency may be involved in the dispatching if specialized equipment (such as cranes) is shared by several agencies (*2*).

Response Priorities

Australian traffic engineers have used large-scale public-opinion surveys to determine subjective hazard ratings of various malfunctions. By a great margin the most hazardous fault was considered to be a turn arrow conflicting with a green signal displayed to the opposite (oncoming) approach (*9, 47*). The surveys found the public to be remarkably aware of the levels of risk associated with traffic-signal failures, and to be concerned not only about the occurrence of such failures but also that they be repaired promptly. Hulscher arrived at a comprehensive set of priorities, shown in Table 1. The top seven are dangerous hazards and receive priority no matter what the importance of the particular intersection. Nine lesser hazards are then listed, with the priority dependent on the level of importance of the intersection. Eight comparatively minor faults complete his scale.

Factors in scheduling response priorities also include minimizing travel time, expected time to be spent at each location, and known traffic patterns (*2*).

Time from Breakdown to Restoration of Service

Failures may not be reported as soon as they occur, or they may be of a nature that cannot be detected by the computer. Therefore it has become common in the United Kingdom to

TABLE 1

PRIORITIES FOR RESPONSE TO VARIOUS TRAFFIC-SIGNAL MALFUNCTIONS (*9*)

Category	Priority	Description[a]
Dangerous Hazard	11	Green signal display to two or more intersecting streets (green all round)
	12	Signals at intersections of two priority roads blacked out
	13	Conflicting green signals (left-turn green arrow with WALK)
	14	Twisted lantern - dangerous
	15	Accident damage creating traffic hazard (e.g., post protruding into traffic lane)
	16	Exposed live wires from damaged post/gantry/controller housing or severed underground cables
	17	Housing door open
Major Status Intersection	21	Timing fault causing serious congestion or delay
	22	Right-turn red or green arrow not operating
	23	Signals not changing (stuck) or not operating (blacked out)
	24	Red or DON'T WALK lamp out (including left-turn arrow)
	25	Erratic timing or skipping of amber or inter-green
	26	Faulty detector
	27	Faulty or missing pushbutton
	28	Skipping pedestrian feature
	29	Accident damage - not dangerous
Priority Road Intersection	31	Timing fault causing serious congestion or delay
	32	Right-turn red or green arrow not operating
	33	Signals not changing (stuck) or not operating (blacked out)
	34	Red or DON'T WALK lamp out (including left-turn arrow)
	35	Erratic timing or skipping of amber or inter-green
	36	Faulty detector
	37	Faulty or missing pushbutton
	38	Skipping pedestrian feature
	39	Accident damage - not dangerous
Other Intersection	41	Timing fault causing serious congestion or delay
	42	Right-turn red or green arrow not operating
	43	Signals not changing (stuck) or not operating (blacked out)
	44	Red or DON'T WALK lamp out (including left-turn arrow)
	45	Erratic timing or skipping of amber or inter-green
	46	Faulty detector
	47	Faulty or missing pushbutton
	48	Skipping pedestrian feature
	49	Accident damage - not dangerous
Other	51	Amber or green lamps out (including left-turn arrows and walk lamps)
	52	Two or more conflicting lamps simultaneously (e.g., red/green, red/amber, and green/amber together)
	53	Faulty illuminated sign (NO RIGHT TURN, etc.)
	54	Missing finial cover
	55	Twisted lantern or target board - not dangerous
	56	Pneumatic detector tread leaving channel
	57	WAIT or bollard lamp out
	58	Any other fault

[a]In the United States, the references to right turn should read left turn and vice versa.

speak of the "mean time of existence" (MTOE) when dealing with signal failures (*45, 47*).

MTOE = time the failure exists before reported + MTTR

where MTTR is the mean time to repair after the report is received.

Blase described an interesting approach to the difficult task of estimating how long a failure may go unreported (*45*). First, he determined from a sample of London signal failures that the MTTR was 6.3 hours. Then he determined that, of the 15,786 failures reported in a recent year, about 2,000 were duplicate reports of the same fault.

> Since a large number of agencies may report the same failure, it is not unreasonable to assume that, once a failure has been reported, there are no constraints preventing it from being reported again.

Blase concluded that there is a probability of 2,000 in 15,786 that a fault will be reported again within the 6.3-hour MTTR. The expected time that the failure has been in existence is the time it takes to achieve a probability of 1 that the fault is reported once. This time is calculated as

$$\frac{15{,}786}{2{,}000} \times 6.3 = 49.7 \text{ hours}$$

Therefore the MTOE of a failure is

$$49.7 + 6.3 = 56.0 \text{ hours}$$

This approach gives an estimate of the upper limit of the MTOE.

Off-Hours Emergency Response

Emergency repairs made outside of regular working hours are a concern because of the expense of overtime pay. Administrators will consider costs heavily in determining the procedure to be followed in handling off-hours trouble calls. These costs are affected by overtime pay practices, which may be controlled by rules of the civil service or unions. For instance, some contracts require pay for a minimum number of hours (as high as three or four) for every call-out after normal working hours, regardless of the time actually taken. Abuses of overtime premium pay have been reported, including unnecessary prolonging of after-hour repair work and deliberate postponement of regular-shift work until the overtime period (*2*).

In some localities the prevalence of crime during nighttime hours is a factor in the decision of whether or not to dispatch repair personnel.

Fulton County, Georgia (Atlanta) recently analyzed seven months of overtime paid in 1983. The Electronics Division manager concluded that overtime pay resulting from emergencies could be reduced by 90 percent if their four crews would work overlapping split shifts, the first beginning before the morning rush hour and the second ending after the evening rush hour each day (*48*).

Corrective Measures

An earlier section explained the system developed for PennDOT to establish three levels of response-maintenance capability (*13*). The International Municipal Signal Association (IMSA) (*3*) offers Trouble Report forms and suggestions oriented primarily to safety measures that should be taken while on a call.

The importance of good documentation on the equipment cannot be overemphasized. Atlanta uses a Keysort System (the McBee Keysort is a manual method of sorting inventory cards) for inventory information. A second repair record inside the controller cabinet is essential so that the first-line repairman can take into account the complaints and repairwork preceding his call.

One critical consideration in response maintenance is the ease of setting the timing on a controller or coordination unit that has replaced a faulty one. Some keyboard-programmed microprocessor units may be difficult for a trouble electrician to time in the field. Robinson, Sanderlin and Associates (*49*) in 1981 devised a Traffic Signal Controller Evaluation Form that looks closely at such characteristics that determine maintainability. Their form allows the agency to rate a controller unit on the following items on a yes/no basis:

Controller Replacement

- Field Serviceable by Trouble Electrician
- Match Existing Timing (Copy Dial Settings)
- Timing Reprogrammed Via Copy PROM
- Timing Reprogrammed Via Keyboard
- Custom Signal Program Reprogrammed Via PROM Replacement
- Standard Signal Program Common to All Controllers

Other

- Bench Serviceable by City Technician
- Regional Service Centers

The measures that can be taken to correct malfunctions or breakdowns include repair, downgrading, flashing operation, and signal shutdown. If it is determined that complete repair cannot be accomplished at the site, then one of the other three alternatives will be chosen.

Downgraded operation retains the green-yellow-red indications, but at a less efficient level than afforded by the signal after complete repair. For example, downgraded operation can result if a replacement controller does not have all of the features of the replaced unit. Downgrading can also be the result of setting the controller to "recall" to a phase that has experienced a detector failure. Other examples include loss of a protect turn phase, of pedestrian indications, or of interconnection circuits (*2*).

Maintenance policies vary from agency to agency as to the decision whether to downgrade or to repair. Some jurisdictions instruct their emergency-repair crews to spend as little time as possible at any one location. A crew performs only the minimum amount of work necessary to restore some kind of signal control; later, a regular maintenance or construction crew completes the repair. This procedure frees the emergency-repair crew to answer another trouble call as quickly as possible; however, the efficiency of intersection operation suffers until the regular crew completes its work some time later. Other jurisdictions follow this "minimum work" procedure only for off-hours trouble calls, or calls made during relatively heavy traffic conditions, or during bad weather, or under some other predetermined conditions. Other agencies attempt to minimize downgrading by specifying that the emergency-repair crew take the time needed to complete the repair during the first visit (*2*).

Placing the intersection on flashing operation allows the controller to be worked on or swapped out for another. If the signals are turned off completely, it will be necessary to control traffic by police or flagmen, or by STOP signs.

Follow-up includes all work scheduled at intersections where the first-line technicians were not able to complete the repairs. After completion of the emergency repairs, or the follow-up work that may have been required, it is particularly important to consider additional inspection to ensure that proper operation has in fact been obtained.

CHAPTER THREE

MAINTENANCE PERSONNEL

The evolution from electromechanical to solid-state designs has caused a corresponding transition in the requirements for maintenance personnel. Appendix C includes example sets of detailed qualifications for the various skills needed to maintain modern equipment. Chapter 6 presents extensive data on ratios of numbers of signals per maintenance staff member.

The maintenance of the 3,669 signals in the City of Los Angeles is accomplished by a staff of 76, of which 61 are journeyman traffic signal electricians and 4 are transportation engineers (*44*). The personnel are organized according to the following specialized functions:

Function	Personnel
Emergency Signal Repair & Routine Signal Inspection	22
Preventive Maintenance	8
Inteconnected Systems Inspection	6
Maintenance Work Orders	6
Wreck Repair	6
Loop Replacement	3
Relamp Program	3
Signal Shop Controller Repair	11
Signal Head Repair	3
Signal Timing (Engineering)	4
Supervision (Direct Full Time)	4
Total	76

It is interesting to note that the 22 persons assigned to emergency signal repair operate as one-man crews. Other cities may prefer two-man crews where personnel are exposed to moving traffic, or where crime is prevalent, or where union rules call for two. Moreover, two-man crews are safer than one-man crews when aerial equipment is operated. Often, one crewman is needed to observe the signals while another performs checks on the controller.

An example of a smaller jurisdiction is DeKalb County, Georgia, in the Atlanta area. With 680 signals, including flashers, DeKalb County has a signal maintenance staff of 27, of whom 25 work on the day shift and 2 are assigned to the evening shift (on one trouble truck). In addition to the Signal Shop Foreman, there are two Electronics Technicians, one of whom is a bench repairman and the other is assigned to do field work. The remainder of the staff includes two senior electricians, 10 electricians, and 13 senior crew workers. They work in crews of four, usually, including one Loop Crew; three Line Crews that perform inspection, preventive maintenance, and installation; and two trouble trucks each manned by a single technician. As in the evenings, the one trouble truck used on weekends has two crewmen.

A jurisdiction that is smaller than DeKalb County is the city of Macon, Georgia. Macon has 174 stop-and-go signals, 39 school flashers, and 26 flashing beacons. Signal maintenance is performed by the Traffic Signals, Signs and Markings Division of the Electrical Department, which is separate from the Traffic Engineering Department. The signal shop has a supervisor and eight workers, and shares a secretary with the sign shop. The workers include a (working) foreman and an electronics technician who is the bench repairman. The work is generally performed by crews of two, each made up of a Technician III assisted by a lower-category technician. The crews rotate in assigned duties so that each technician receives broad experience, including installation work. All of the workers are assigned to the day shift. After-hours trouble calls are taken by one worker who is given that duty for a week at a time and receives extra compensation of 10 hours for the week at a time-and-a-half whether called out or not.

FOUR CATEGORIES OF MAINTENANCE SKILL

In 1977, Stout et al. (*50*) identified four categories of maintenance skill required for traffic control systems. The categories were described in terms of the equipment:

- Electromechanical devices, such as pretimed controllers
- Electromechanical/electronic devices with vacuum tubes
- Solid-state devices with linear circuitry
- Solid-state devices with digital circuitry

Table 2 describes these categories in more detail.

TABLE 2

CATEGORIES OF MAINTENANCE SKILL (*50*)

Maintenance Skill Category	Equipment Description
1	Electromechanical devices, such as pretimed controllers, synchronizers, coordination units, and other devices operating by mechanical and electromagnetic principles. (An example is the Eagle Model EF-20 pretimed controller.)
2	Devices operated by using electronic principles accomplished by means of vacuum tubes in conjunction with electromechanical devices. (An example is the Automatic Signal Model 1826 actuated controller.)
3	Devices operated by means of solid-state linear circuitry. These are analog devices. (The Automatic Signal Model ST 827 controller is an example.)
4	Devices operated by means of solid-state digital circuitry. These generally employ LSI and TTL techniques. (The Econolite D-8000 controller or microprocessor controllers are examples.)

TRAINING

Stout et al. (*50*) described the maintenance personnel qualifications and training for each category as follows:

- Entry-level requirements
- Familiarization-training time needed
- Training time for each specific device
- Minimum experience to be considered a skilled technician

Table 3 details the qualifications and training for each of the four maintenance-skill categories. Stout et al. also described the training needed for a technician to advance from one category to another.

Gibson (*51*) described the training required for maintenance technicians who are to work on the Model 170 controllers jointly developed by the California D.O.T. and the NYSDOT (*52,53*). The suggested background includes either the Heathkit 6800 course or the Motorola 6800 course, plus a basic course in microcomputer programming, and a follow-up course entitled "Advanced Signal Repair" as offered to west coast repair-facility technicians. Figure 1 shows the Model 170 and its cabinet (*54*).

Scheck (*26*) observed the maintenance activities at the Ohio D.O.T. signal shop and studied the reference manuals provided by equipment manufacturers. He then prepared a manual of detailed procedures that represent good practice consistent with the available tools and instruments. The manual covers many models of electromechanical and solid-state controllers, various load relays, and a number of loop-detector electronics units. A formal training program was presented to 30 participants representing all districts and the central office, to familiarize maintenance personnel with microprocessor-based controller and diagnostic equipment.

Short courses or training seminars are presented by the IMSA in connection with their annual meetings in August. Other courses aimed specifically at maintenance technicians are presented by certain manufacturers at various locations around the country.

As a practical matter, in-service training is often the most available way to upgrade skills. One way to fund such training, practiced by the North Carolina D.O.T., is to specify in equipment-acquisition contracts that the supplier furnish training along with the hardware. (See Appendix H for the N.C.D.O.T. specification for such training.) Maryland has a practice of furnishing training, at its expense, to its cities. In North Carolina, training programs are planned and arranged by the North Carolina division of the Southern Section of the ITE, funded by the Governor's Highway Safety Program, and presented by technical experts from the N.C.D.O.T.

A key point is that training materials need to be attractive and easy to read. Vest-pocket summaries liberally laced with cartoon-style sketches make a readable format that is much more likely to find its target (*55*).

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. A survey taken in connection with the preparation of *Synthesis 22* (in 1974) found various procedures on staffing multi-shift operations. One jurisdiction has a normal complement of personnel for the first shift, half that number for the second shift, and a skeleton crew for the third shift. Other jurisdictions staff the first two shifts fully and rely on standby arrangements for the third shift. Some have complex duty rosters for rotating personnel among the various shifts.

Standby procedures to be followed outside of regular working hours vary widely. The standby crew may be the only maintenance force available; alternatively, a skeleton crew may be kept on duty, reinforced by the standby crew only when the workload requires. Another scheme calls for all regular maintenance workers to be assigned responsibility for a number of installations near their homes. A third plan is for a foreman to be on call and responsible for making the necessary arrangements for the required repair work. Still another procedure has the dispatcher telephone individuals from a priority call list that is rotated at regular intervals. Procedures may change at a certain time of day (such as at midnight) or they may differ between weekday nights and weekends (*2*).

License and Union Requirements

A journeyman electrician's license is required by some agencies to be held by all maintenance personnel, whereas other jurisdictions may require this only of foremen or of some senior personnel. Licensing may be required for hiring or for promotion, depending on local practices and applicable state laws.

Licenses issued by the Federal Communications Commission (FCC) are required for personnel involved with the operation and maintenance of some types of control, detection, and interconnection equipment. Some agencies reimburse their personnel for the cost to obtain and renew FCC licenses.

Those jurisdictions that are unionized may have electrical craft unions, general industrial unions, or unions of public employees. Where unions exist, the signal maintenance manager should see that the union contract provides adequately for this

TABLE 3

MAINTENANCE PERSONNEL QUALIFICATIONS AND TRAINING (*50*)

Benchmark	Description
Maintenance Category 1	
Entry Level Requirements	Knowledge of electricity and mechanical theory equivalent to that obtained in a one-year technical school or related training on similar equipment, such as company-provided training in typewriter repair, cash registers, etc., and one to two years experience. Must know basic electricity, have the ability to read wiring diagrams, check circuit continuity, and understand rotating parts.
Familiarization Training	One month
Specific Device Training	One week intensive training on each type of device.
Minimum Experience to Be Considered Skilled Technician	Three months plus two weeks per device serviced.
Maintenance Category 2	
Entry Level Requirements	Military electronics school or a nationally recognized electronics school with emphasis on electronic component maintenance including concentrated training in vacuum-tube technology and two years experience in maintaining similar types of equipment. In lieu of formal training and experience stated above, four years of maintenance experience on similar types of equipment will qualify the applicant.
Familiarization Training	Three weeks
Specific Device Training	One week intensive training on each type of device.
Minimum Experience to Be Considered Skilled Technician	Four to six months plus one month per device serviced.
Maintenance Category 3	
Entry Level Requirements	Military electronics school or a nationally recognized electronics school with emphasis on electronic component maintenance including concentrated training in transistor technology and linear circuits and two years experience in maintaining similar types of equipment. In lieu of formal training and experience stated above, four to five years of maintenance experience on similar types of equipment will qualify the applicant.
Familiarization Training	Two weeks
Specific Device Training	One to two weeks intensive training on each type of device.
Minimum Experience to Be Considered Skilled Technician	Three to six months plus one month per device serviced.
Maintenance Category 4	
Entry Level Requirements	Military electronics school or a nationally recognized electronics school with emphasis on electronic component maintenance including concentrated training in digital logic and in the manual skills necessary to service equipment. In addition, experience in the maintenance of similar types of equipment for two years or five years of maintenance experience on similar types of equipment in lieu of formal training.
Familiarization Training	One month
Specific Device Training	One to two weeks intensive training on each type of device.
Minimum Experience to Be Considered Skilled Technician	Three to six months plus one month per device serviced.

work. Otherwise, signal maintenance may be hampered or made unduly costly by citywide union contracts that do not account properly for these requirements (*2*).

PERSONNEL RECRUITMENT AND RETENTION

A perennial problem is the inability of many governmental agencies to compete in the labor market because they cannot pay prevailing wage rates. Proper maintenance of sophisticated traffic-signal systems requires salary schedules higher than normal maintenance or electrician rates. Signal-maintenance organizations compete with electrical contractors, utility companies, and electrical and electronic manufacturers. In some areas with large industrial plants or a great deal of construction under way, certain skills may be completely unavailable.

A state or local maintenance organization may find it difficult to compete for personnel with another governmental agency offering higher pay. A state highway agency using a wage scale that is uniform statewide may be able to compete satisfactorily in the rural areas, but may fail to retain trained personnel in the larger urban areas where local governments have a higher pay scale.

Substandard wage scales may force an agency into hiring inexperienced personnel, who then must be trained at some expense. Once they are trained it is vital to retain them by providing an attractive package of salary scale, working conditions, and fringe benefits. Otherwise the training program becomes an expense with little or no return to the agency providing it (*2*).

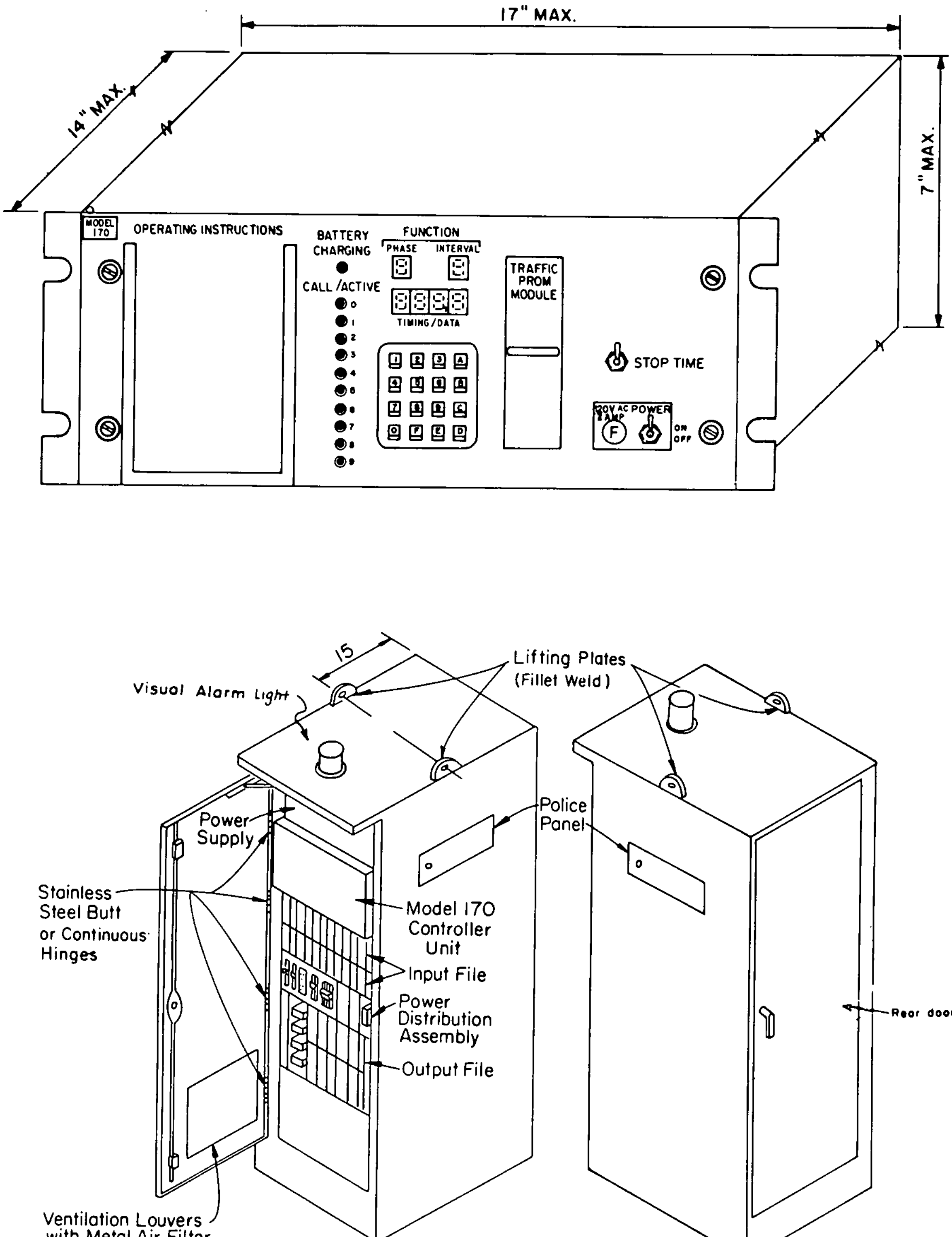


FIGURE 1 Model 170 controller and cabinet (*54*).

CHAPTER FOUR

MAINTENANCE FACILITIES AND EQUIPMENT

This portion of the synthesis describes signal repair shops, field equipment, communications from person to person, and the management of spares and supplies. The most noteworthy changes in the past decade have been the development of CRT (terminal) monitoring of malfunctions from the signal-repair shop, and the use of microprocessor-based diagnostic equipment in both the field and shop.

SIGNAL REPAIR SHOPS

Acceptance testing, major reconditioning, overhaul, repair, and bench testing of traffic-signal equipment are done at a signal repair shop. Most agencies have only one. Figures 2–8, and the others in this chapter, show good examples of the facilities at a modern signal shop.

Three types of testing are performed at a shop:

- Acceptance testing at time of purchase
- Diagnostic testing for malfunctions
- Acceptance testing after repair

Chapter 6 has a section entitled Call Rates that reports the results of the stringent acceptance-test programs carried out by several states at the time of purchase. The importance of these programs in reducing the frequency of trouble calls can hardly be emphasized enough.

CRT Monitoring of Malfunctions

One of the principal advantages of computer-based traffic control systems is their ability to monitor the controllers and detectors for malfunctions. An alarm message can be transmitted from the computer to both the traffic engineer's office and the signal shop, where an appropriate input/output device such as a CRT unit can be located.

Tools and Conventional Test Equipment

The IMSA Manual (*3*) presents a detailed list of the exact tools required to outfit a signal shop. Conventional test equipment for traffic-signal work consists of custom-made equipment for signal testing and also such standard items as digital multimeters, oscilloscopes, and substitution boxes. At each of the several work stations at the signal shop will be found test panels

FIGURE 2 Technician testing a loop-detector unit in Macon, Georgia.

FIGURE 3 Technician using NEMA test board with a controller in Macon.

and meters to test and troubleshoot a specific type, or family of types, of control equipment. Test boards may be fabricated by shop personnel or purchased. The number of work stations required for each type of control equipment depends on the number of units in operation, the shop-overhaul frequency, the expected failure rate, the average time spent on each overhaul or repair, and the utilization (number of shifts) of each station. Additional stations will be required if acceptance testing of new equipment is to be done (*2*).

Equipment for Microprocessor-Based Controllers

Gibson (*51*) listed the equipment required for a shop to test the Model 170 controller. The list would apply equally well to other microprocessor-based controllers, such as those meeting the NEMA standards.

- Good controller of same type + cabinet fully loaded
- Oscilloscope

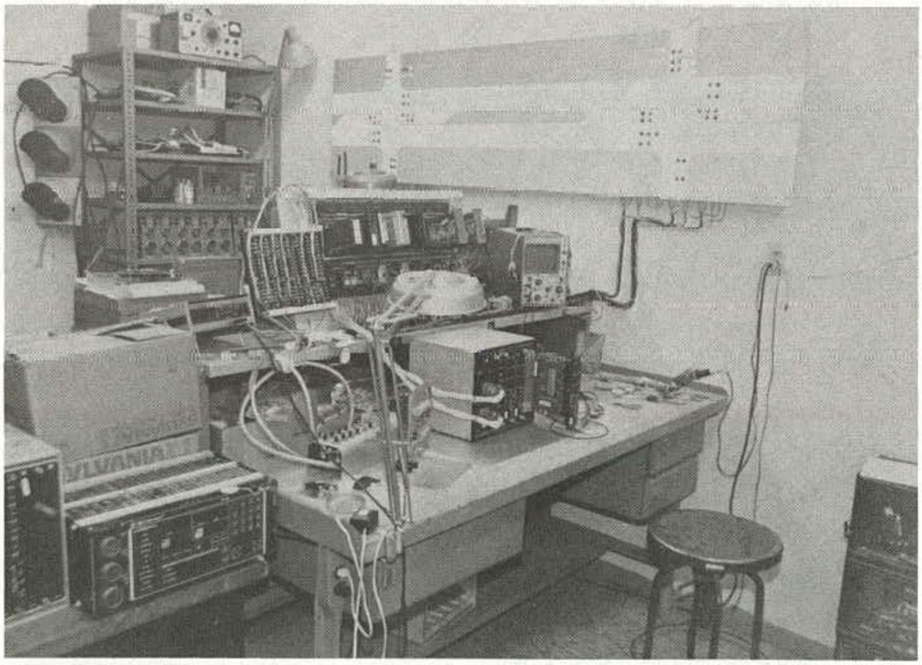


FIGURE 4 Controller repair bench at the West Virginia Department of Highways.

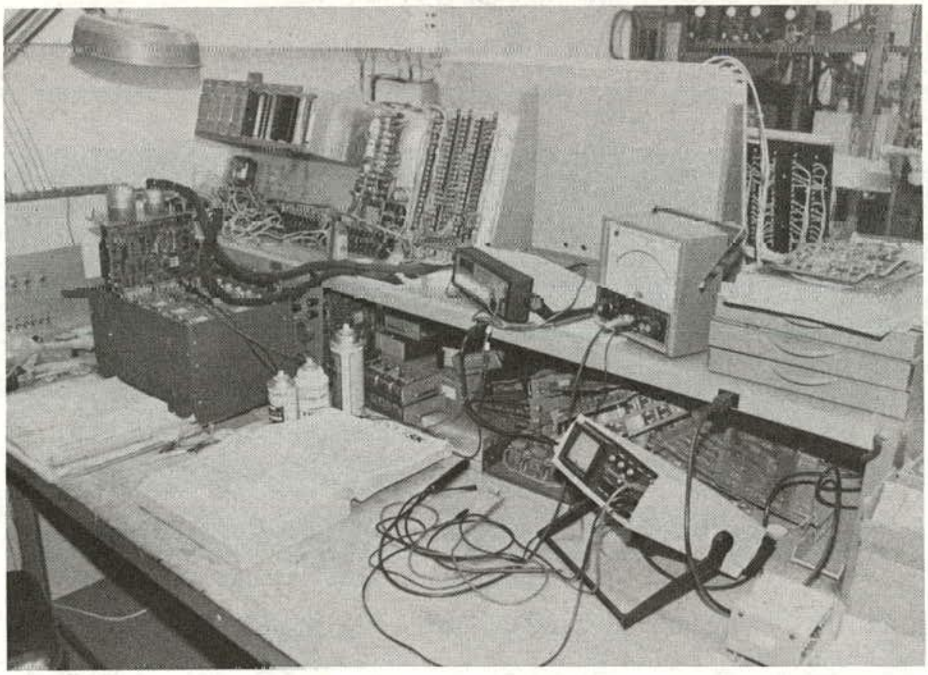


FIGURE 5 Another controller repair bench at West Virginia.

- Ohmeter
- Frequency tester (for modem)
- Good DC power supply, variable 0–32 volt
- Test panels
  - Conflict monitor tester
  - Cabinet wiring tester
  - Load switch tester
  - Magnetometer tester
  - Magnetic tester
  - Loop detector tester
  - Loop tester
- PROM programmer with eraser (for copying, verifying, and erasing UV EPROMS)
- Environmental test chamber
- 6800/6809 microcomputer—Smoke Signal, Gimix, Hazelwood, Motorola

FIGURE 6 Electromechanical dial units are cleaned every 9 to 12 months at the City of Milwaukee signal shop.

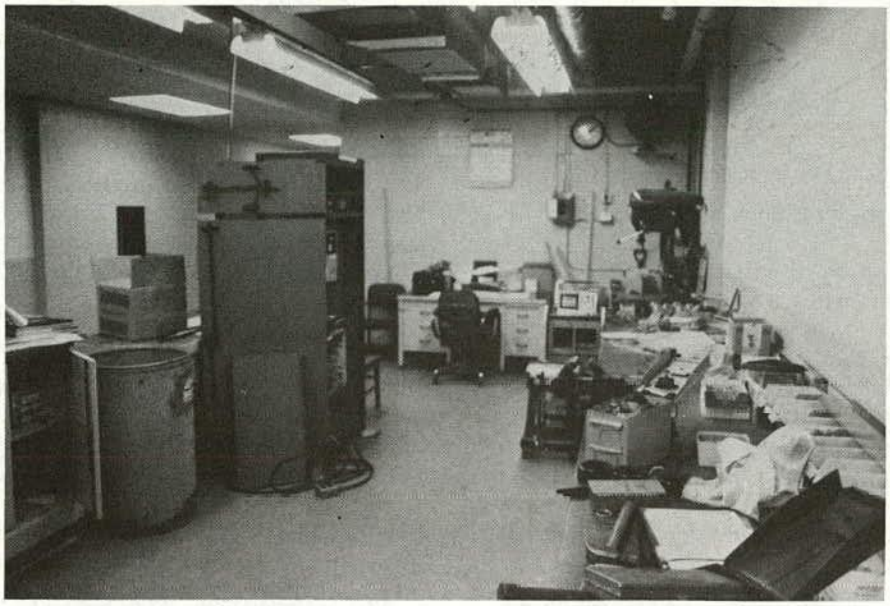


FIGURE 7 Area for construction and minor testing of electromechanical equipment in Milwaukee.

Figures 9 and 10 are photos of environmental test chambers. Comparably stringent environmental test procedures are specified for both Model 170 and NEMA-standard controllers. Figure 11 shows a typical test diagram for carrying out the environmental checks specified by NEMA (*56*).

The environmental test chamber is used to heat controllers to 160°F (71°C) and to cool them to −30°F (−34°C). At each of these temperatures the units are made to cycle for about 24 hours, after which they are tested while still in the chamber at temperature. A CRT reports the test results to the operator.

A high-quality variable power supply is also needed, to test the range of line voltage over which a controller will operate.

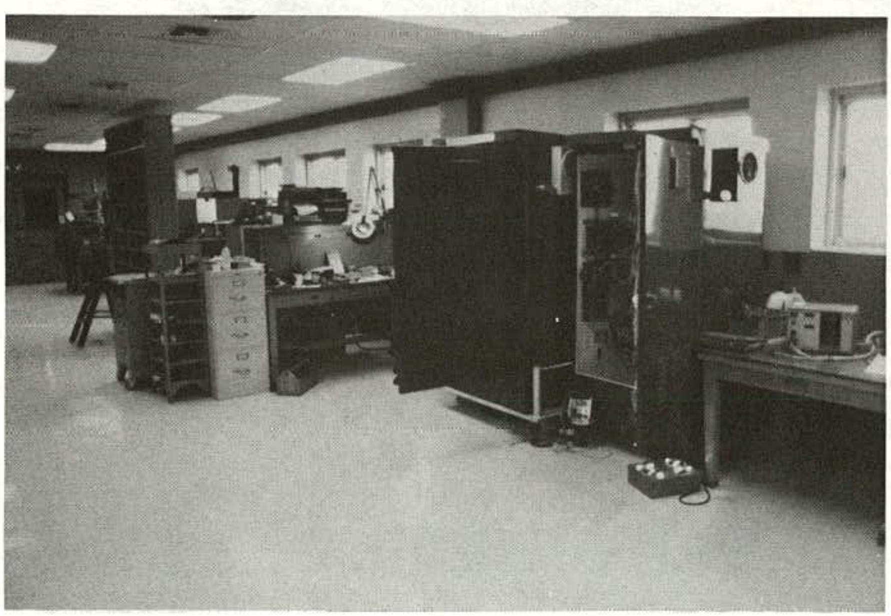


FIGURE 8 Area for construction and maintenance of solid-state equipment in Milwaukee.

The power supply is connected to the power leads of a controller under test and the voltage is slowly raised from zero to 130 VAC and then lowered.

Figures 12 and 13 show controllers awaiting testing and repair.

Diagnostic Equipment for Both Shop and Field

Some microprocessor-based controllers can be analyzed to isolate a malfunction through the use of a special diagnostic programmable read only memory (PROM) module. These controllers were designed to allow nonengineering personnel working in the shop or under difficult conditions in the field to isolate malfunctions to particular modules or printed circuit cards. For this purpose the normal PROM module (with the program for that intersection) is replaced by the diagnostic PROM module, which contains troubleshooting routines provided by the state to enable the automatic isolation of a defective circuit or function within the printed circuit module. The technician simply activates a switch that advances the diagnostic PROM from one test to the next. Indicator lights show whether each test was passed or failed.

Another microprocessor controller has available a maintenance kit based on a diagnostic PROM module. The test software includes both an automatic and manual mode of operation. A number of features permit sophisticated testing utilizing simple manual operations.

Still another microprocessor-based controller can be used with diagnostic PROMs that eliminate most of the guesswork and tedious, systematic switching of components and modules required by normal troubleshooting procedures. The diagnostic PROM is applicable to either bench or field testing, but is most effectively used in the shop to track malfunctions down to the component level after the defective module has been located and exchanged in the field. One of the PROMs cycles the controller through all the tests again and again, for hours or days, until an intermittent failure reappears and the bad component is located.

Scheck (*26*) developed a controller exerciser/diagnostic unit that has a built-in test procedure to check the timing, the ability to skip phases, the response to calls, conflicts in signal displays, and missing overlap signals. The units are designed for either field or shop use. For field use the controller can be left in service, but the actuations from traffic will be intercepted and the controller will respond to actuations generated by the instrument.

Scheck reported that the exerciser/diagnostic unit has the following potential benefits (*26*):

Speeds up the process of checking timing in the field.
Documents that the controller was functioning in a normal man-

FIGURE 9 Environmental test chamber at New York State D.O.T. facility.

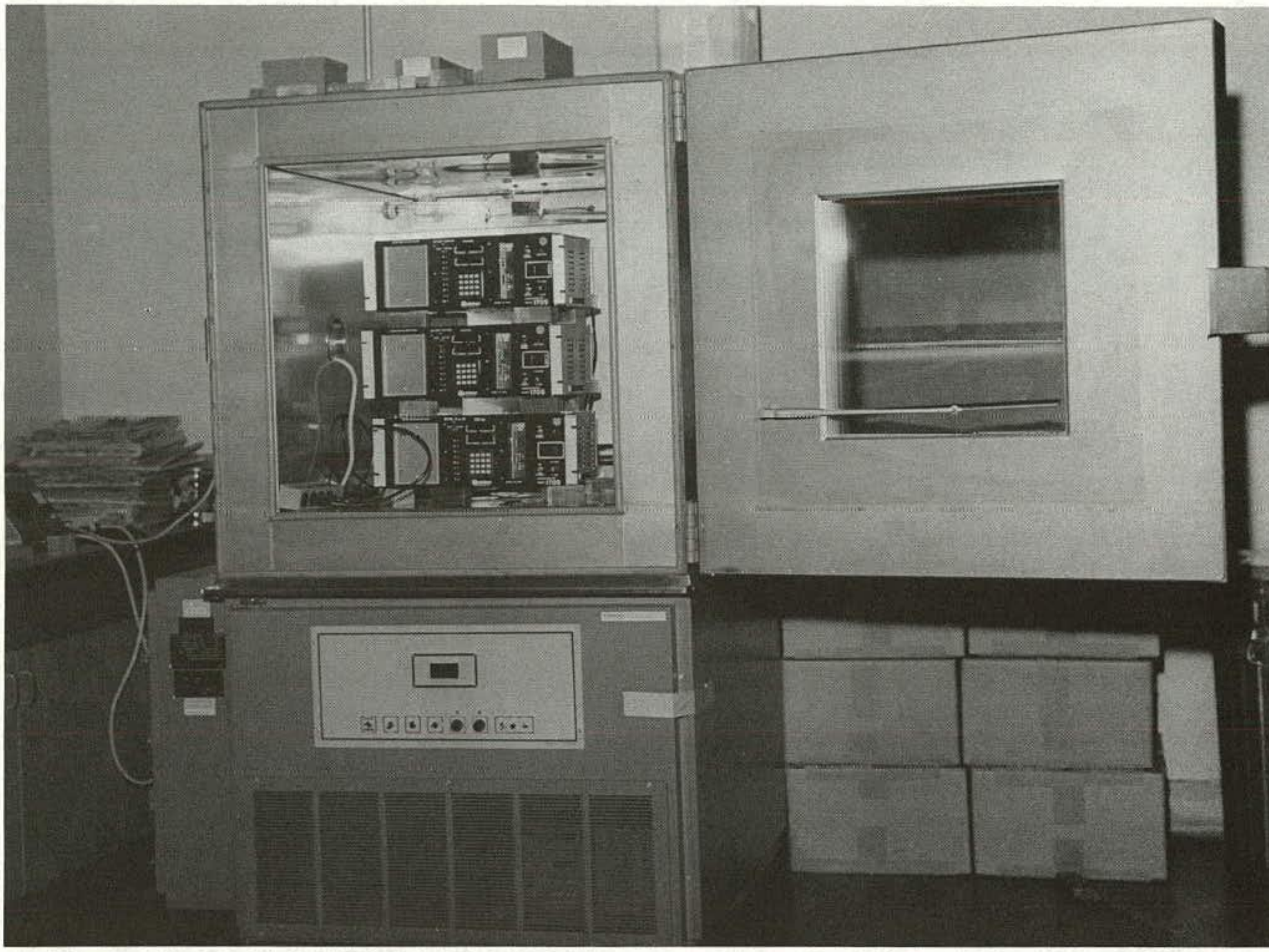


FIGURE 10 THERMOTRON environmental test chamber at City of Los Angeles holds three Model 170 controllers.

ner during routine inspection of the signal installation. This documentation should assist the agency in defending against liability suits alleging negligence.
Monitors and documents the results of shop burn-in tests of repaired or new controllers. This application uses the repetitive or long-term test capability of the unit.

Figures 14 and 15 show controller test units.

Storage Requirements

The signal shop will have storage facilities for tools, equipment, parts, supplies, and equipment awaiting repair. Additional storage space may be needed at a separate warehouse.

Agencies responsible for a large geographical area may establish branch warehouses that stock items in frequent demand. The main warehouse is the central receiving point and principal depository. In addition to keeping the satellite facilities stocked, the central facility inspects all incoming material.

Inasmuch as maintenance trucks cannot carry a complete inventory, access to the storage facilities must be available around the clock (*2*).

Figures 16–20 show equipment stocked at several signal shops.

FIELD EQUIPMENT

Field equipment includes vehicles and aerial equipment, tools, test equipment, and miscellaneous items such as hard hats and safety vests.

Vehicles and Aerial Equipment

The manual published by the IMSA in 1981 (*3*) includes an entire section to assist the reader in the selection of utility-type trucks, bodies, aerial lifts, and related equipment used in the installation and maintenance of traffic signals. The IMSA points out that there are three basic determinations that should be made before purchase:

Adequate work performance
- Sufficient gross vehicle weight (GVW) rating
- Aerial lift capacity
- Platform work area

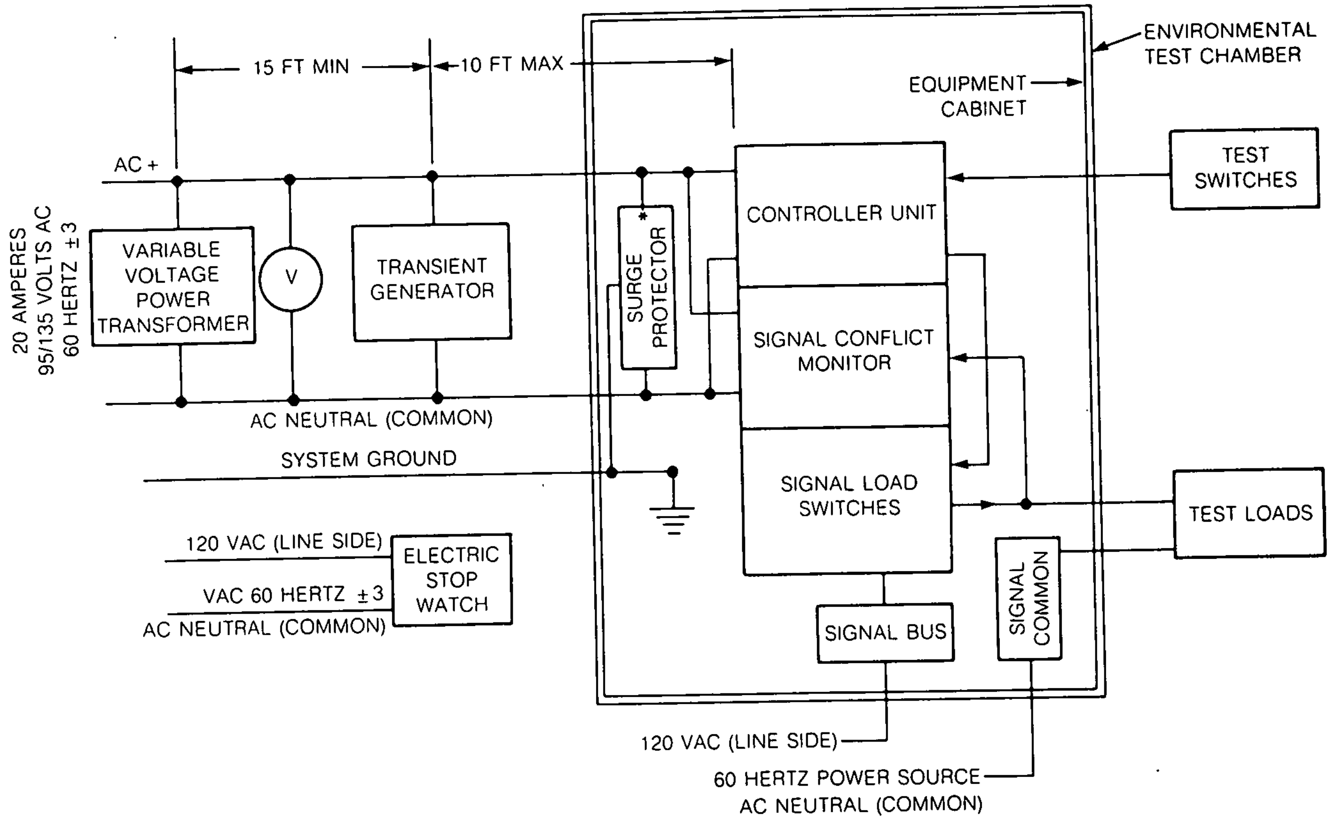


FIGURE 11 Typical diagram for the performance of NEMA environmental test (*56*).

Proven product
  Certify number of units in service
  Reliability of design
  Safety features
Service available
  Service contract
  Parts and replacements
  Warranty or guarantee

The IMSA (*3*) provides suggested specifications for the following types of aerial equipment:

- Hydraulic aerial tower lift with revolving platform
- Aerial basket equipment articulating over center, two-man operation
- Aerial basket equipment, telescope type, one-man operation
- Revolving aerial ladder equipment
- Hydraulic rotating derrick and digger
- Combination aerial beam with derrick and digger operation
- Aerial hydraulic section mast platform—all purpose

The OSHA rules and regulations pertaining to aerial lifts are reproduced in that section. It goes on to describe the details of add-on compartments for pick-up bodies, utility service bodies, maintenance bodies (utility service bodies with and without a superstructure), and crew-compartment bodies. The section concludes with a listing of various types of related equipment, such as trenchers, air compressors, augers, cable-handling equipment, etc., and an offer to provide details of each upon request to the national IMSA office in Fort Worth, Texas.

Shreveport, Louisiana has developed a repair van prompted by the need for an indoor soldering area at the intersection (Fig. 21) (*57*). The development of the unit was prompted by the home-service television-repair vans in use around the city. The van carries about $2000 worth of "off the shelf" test equipment and a staff-built intersection simulator. Shreveport has found that the van eliminates the need for a second technician when on-site repairs are needed. Also, the time required to locate and correct the problem has been greatly reduced, cutting costs of field service by 25 percent.

Field Diagnostic Equipment

Scheck has pointed out that "the most serious and costly maintenance problems are long-term intermittent failures. A system to monitor such installations would be a great help in field maintenance" (*26*). The equipment he describes seems to be a step in that direction.

Staunton has developed signal controller operation recording equipment (SCORE) that monitors controllers in the field (*58*). It was developed for research investigations but could also be used for maintenance and acceptance testing. The SCORE unit is intended to be located in a van or car trunk, with lead wires running to optical couplers at the controller. There is no interference with controller circuits. The unit provides a time-related paper record of activity on as many as 20 controller circuits. SCORE checks out timing functions but does not attempt to

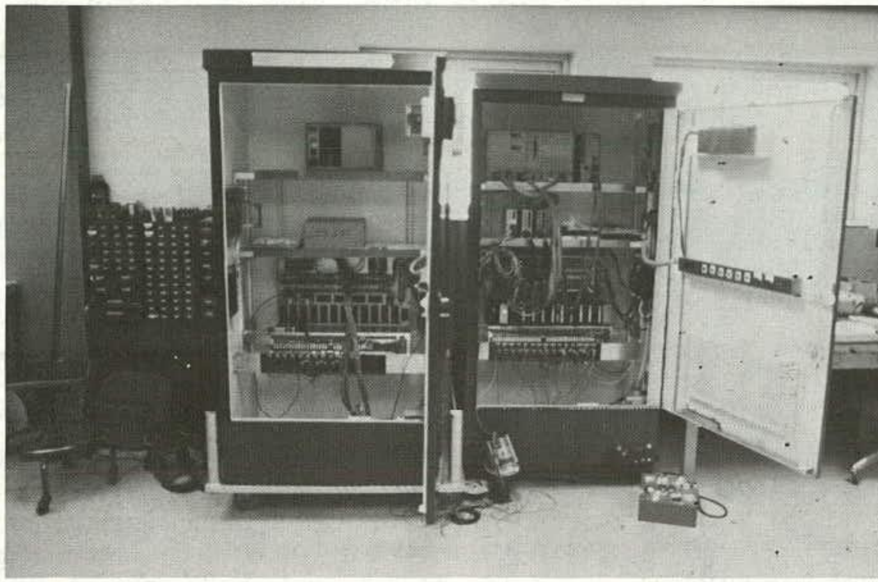


FIGURE 12 Solid-state pretimed and actuated controllers in City of Milwaukee cabinets.

diagnose malfunctions to be caused by a certain board or component. The actual connection of SCORE requires from 10 minutes to an hour, depending on controller model. In an eight-hour working day useful data can be recorded at four average intersections.

Staunton has also developed a side tone unit (STU) that attaches optically to the call light of a loop-detector electronics unit (*59*). When the light goes on, the STU emits a high-pitched tone, allowing the technician to concentrate visual attention solely on the traffic.

The Model 170 controller developed by California and New York has diagnostic capabilities as noted before. These units can recognize and correct detector malfunctions and internally created (hardware) conflicts (*60*). The 170 microcomputer continuously tests itself for faults (soft failures) of the detectors and communications interface (*61*). Isolation of a malfunction (hard failure) is accomplished through the use of a special diagnostic PROM module that replaces the normal (street) PROM for purposes of troubleshooting. The diagnostic PROM contains troubleshooting routines to enable the automatic isolation of a

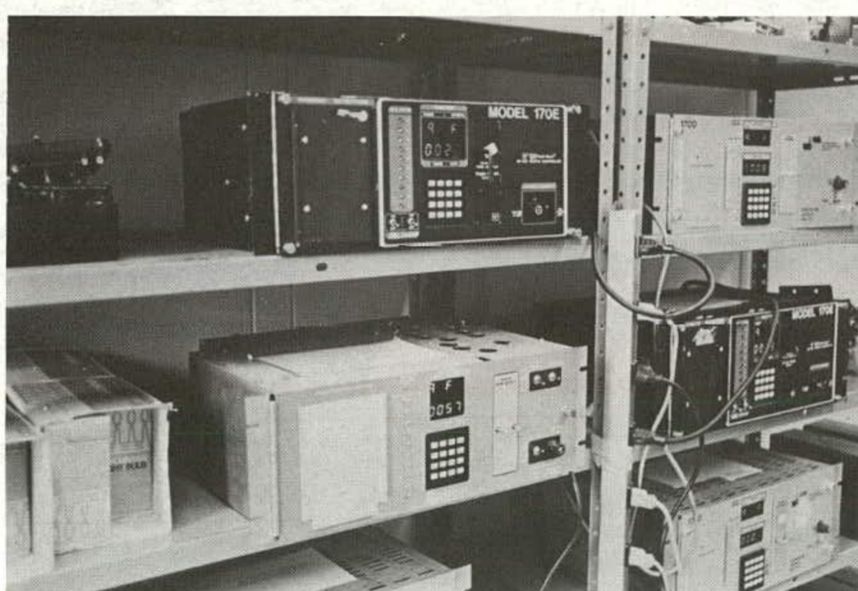


FIGURE 13 Model 170 controllers awaiting repair and testing at New York State D.O.T. facility.

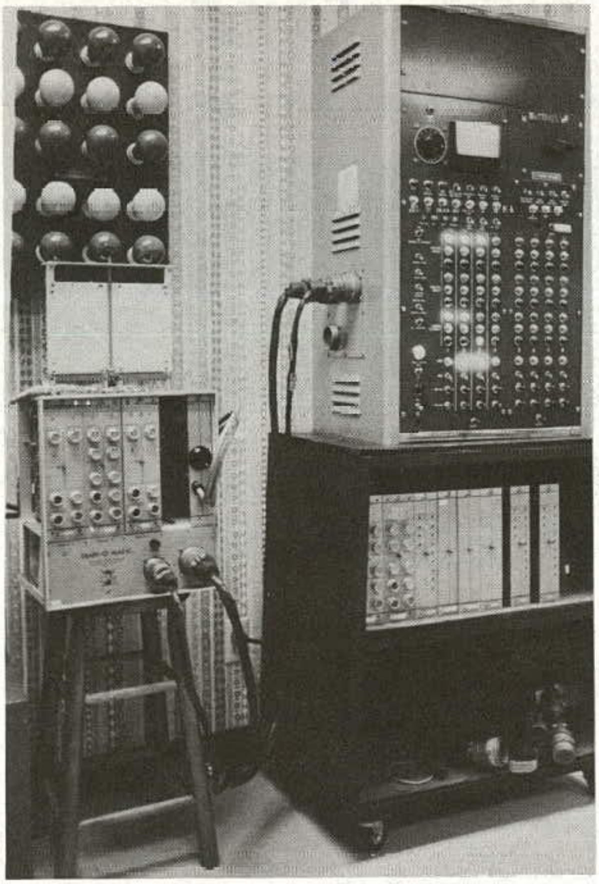


FIGURE 14 Controller test unit in Macon, Georgia.

defective circuit or function within a printed circuit module. The diagnostic PROM has 4K bytes (4096 characters) of memory, and has front-panel indicator lights to show any voltage deviations from the controller's power supply (*54*). Other indicators show the results of tests that time the intervals.

Similar features are also available with NEMA controllers. In Chapter 2 there was described a "closed-loop system" designed for use specifically with NEMA controllers. During working hours the on-street master detects and identifies errors or malfunctions and transmits reports back to a manned central office. During off-hours the system can activate the "beeper" carried by the technician on call. The technician can use a remote console to dial up the system from a telephone at home and take remedial action such as placing an actuated phase on recall.

COMMUNICATIONS

This section pertains to communication from person to person, as by the two-way radios used by nearly every jurisdiction. Communications are required to dispatch maintenance personnel, keep responsible officials informed, and coordinate personnel and materials.

Two-way radios may be supplemented by conventional and hot-line telephones. Teletypewriters and facsimile have been used occasionally between a central control facility and a maintenance contractor, or to interconnect area control centers. State highway agencies have used microwave transmission between area headquarters.

Maintenance of signal systems may be expedited by hand-held walkie-talkies or citizens-band transceivers. Almost all computerized systems have telephone terminals in the curbside cabinets to facilitate communication with the signal shop or the traffic engineer's office.

Warehouses and shops are usually provided with public address systems, paging systems or other methods of internal communications (*2*).

SPARES AND SUPPLIES

The number of spares is set so as to ensure a fairly high probability of having a replacement unit available when needed. They will be available for immediate replacement if they are carried on the maintenance truck.

The required number of spares can be reduced if equipment is standardized. Loop-detector units have long been interchangeable among the various manufacturers. In the past, most jurisdictions attempted to standardize on a single make and model of controller, but low-bid regulations forced most maintenance organizations to purchase, and stock spares and parts for, several different types of equipment. Some agencies were able to fabricate adapter cables or connecting harnesses that

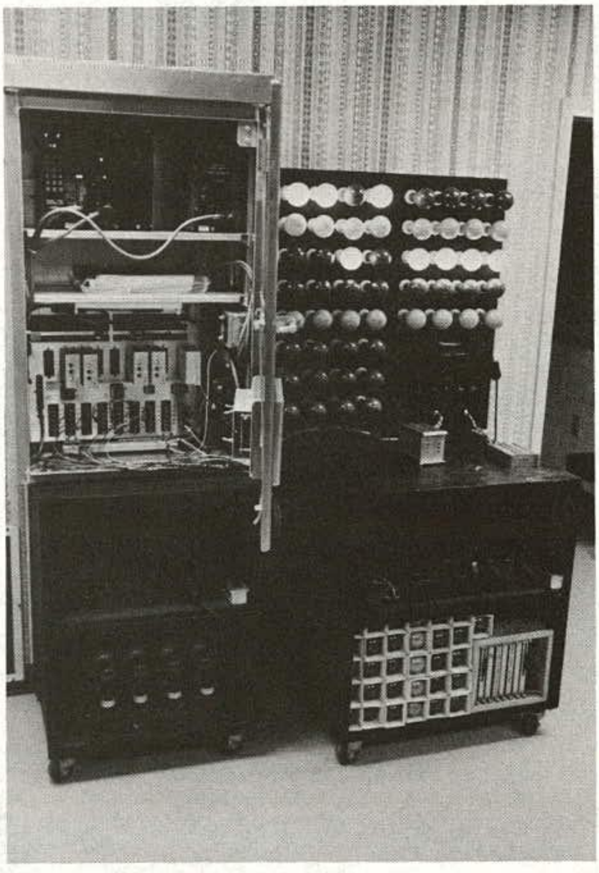


FIGURE 15 Another example of a controller test unit in Macon.

FIGURE 16 Spares stacked at a signal shop in Macon, Georgia.

permitted interchange of some types of controllers. In 1976 the National Electrical Manufacturers Association (NEMA) published controller standards spelling out input/output connections to promote interchangeability. At the same time, the states of California and New York followed a parallel course in developing the Model 170 controller. All 170s are interchangeable at the unit (not board) level, but as of 1984 they do not interchange with controllers produced to NEMA standards.

The IMSA (*3*) has determined national averages for the number of spare units required for the number of units installed, and for the ratios of dollars spent on spare parts, as follows:

Electromechanical pretimed—one for ten
Electronic (vacuum tubes)—one for ten
Solid state—one for fifteen

In-transit spares and replacement equipment need secure storage. Agencies will want to have policies on shock-absorbing carriers, tie-down methods, and so on, to ensure that damage does not occur during transit.

Equipment records and inventories are discussed in Chapter 7, Management Control, under the heading Administrative Control.

SAFETY EQUIPMENT FOR WORK IN THE ROADWAY

Whenever traffic must be moved through or around traffic-signal maintenance operations, the traffic control devices must conform to the *Manual on Uniform Traffic Control Devices,* Part VI, "Traffic Controls for Street and Highway Construction and Maintenance Operations" (*62*). This Part sets forth basic principles and prescribes standards for the design, application, installation, and maintenance of the various types of traffic control devices required for maintenance operations. The *MUTCD* provides details on the deployment of the worker sign, cones, barricades, and other devices.

The IMSA Manual of 1981 (*3*) presents a number of specific guidelines for protection of the worker, the traffic, and the pedestrian. It emphasizes the importance of (a) wearing safety vests, (b) avoiding blocking a larger portion of a lane than is needed at that time, and (c) closing truck doors, tool lockers,

FIGURE 17 Storage for repaired parts at the West Virginia Department of Highways.

FIGURE 18 Electromechanical supply rack in Milwaukee containing dials, relays, and other devices. Units to the left are to be cleaned; those to the right have already been cleaned.

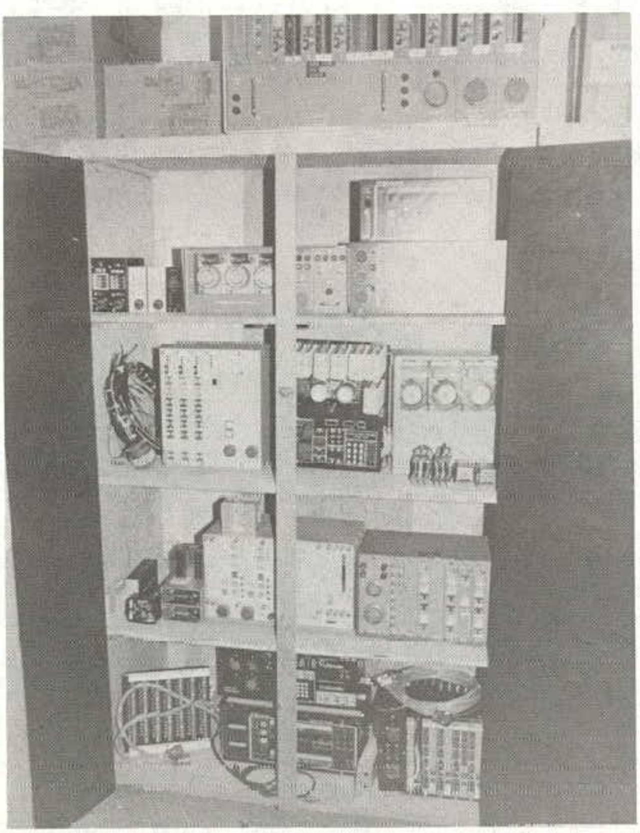


FIGURE 19 Inventory cabinet of controllers in West Virginia.

cabinet doors, hand holes, etc., to minimize hazard to the passing public. When working on any electrical apparatus that has power on, the technician should wear rubber gloves and take other appropriate measures to prevent electrical shock (*63*). Where a traffic signal has been knocked down, the technician should be positive that all the power is removed before attempting repair. Where poles are used jointly by the power company and the traffic department, it is often the case that very high voltage is involved. Before any repair work is started, it will be necessary to contact the power company for assistance or to disconnect the power source.

The technician should make a check with a voltmeter if there is any question of the power source. There have been instances of inadvertent connection of a signal to a street light circuit, the high leg of a three-phase four-wire system, and a 480-volt single-phase circuit, for example (*3*).

FIGURE 20 Small-hardware storage in West Virginia.

FIGURE 21 Shreveport's maintenance van carries testing devices, work benches, and spare parts (*57*).

CHAPTER FIVE

TYPES OF MAINTENANCE ORGANIZATIONS

After discussing the importance of fixing maintenance responsibility, this chapter explores the various potential locations for the signal-maintenance function. Contract maintenance is covered, including its use with computerized signal systems.

FIXING MAINTENANCE RESPONSIBILITY

The FHWA's *Traffic Control Systems Handbook* (*5*) emphasizes that "a leading rule in the management of maintenance activities is that responsibility must be fixed for each individual element of the maintenance program." Computerized signal systems, in particular, may involve a number of agencies and vendors in the acquisition and maintenance of the computer and its peripherals, the communications modules and lines, detectors, controllers, etc. When a failure occurs it is important that "finger-pointing" be avoided by having unquestionably fixed in advance the responsibility for each element of the maintenance program.

LOCATION OF SIGNAL-MAINTENANCE FUNCTION

The maintenance function should be located within the traffic unit, but there are some agencies that locate it within the maintenance unit, within the electrical services unit, or contract it to outside agencies. Although there may be examples of success with these latter arrangements, it is definitely desirable that there be a close interrelationship between signal-maintenance management on the one hand and signal design/operation on the other. Preferably, one manager in the traffic unit should have management and control of both functions. The location of the maintenance function in another unit of the city organization, separate from the traffic engineering office, may create a situation in which the efficiency and safety of traffic flow are not adequately emphasized.

Occasionally the signal-maintenance function is assigned to a maintenance unit. The justification for this is that the nonelectrical work in maintaining signals is similar in duties and equipment to the other work performed by the maintenance unit. Such an assignment is somewhat more common with state highway agencies than with local governments. The responsibility for signal maintenance may rest at the state level with a Bureau of Traffic, whereas at the district level the maintenance work may be assigned to a Bureau of Maintenance. This division of responsibility is more common where there are only a few signal installations in the district or when the district does not have a full-time traffic engineer. In those circumstances a number of operating economies may be realized because of more efficient utilization of manpower and equipment. However, location of the maintenance function within a Bureau of Maintenance may impair the overall coordination and control of the signal maintenance effort and may lead to delays if there are competing demands for the same maintenance resources. Moreover, the quality of the electrical work may not always be adequate. *Synthesis 22* noted that "several jurisdictions, recognizing this problem as well as the traffic engineering effects of the highway maintenance work, have combined the traffic and maintenance functions into a Bureau of Highway Operations, which also may be assigned other related functions" (*2*).

Another alternative is to place the signal-maintenance function within an "electrical services unit." Such a unit may be organized along functional lines (emergency repair, preventive maintenance, follow-up work, etc.), or it may be divided according to type of system (signals, lighting, etc.), or the arrangement may be a combination of the two (*2*). In the smaller jurisdictions an electrical services unit may be responsible for the electrical maintenance of elevators, pumps at sewage lift stations, etc. Individual members of the maintenance force may find themselves "jacks of all trades" within the electrical field, lacking the high degree of skill and experience required for the maintenance of traffic signals.

CONTRACT MAINTENANCE

Currently, the need for contract maintenance is greatest where high-technology hardware, such as computers and communications modules, are involved (and, of course, leased telephone lines must be maintained by the public utility). However, there are situations involving noncomputer-based equipment where contracting is advantageous. The responsibility for overseeing the work of the contractor and enforcing the specified response times, etc., remains with the traffic unit.

Regarding general maintenance (as contrasted with specialized work on computer equipment), two types of contracts can be considered. In the first, the contract is between two separate governmental organizations with overlapping jurisdictions. Under this arrangement a city may maintain the signals installed by a state highway agency within its corporate limits, or the state may maintain signals installed by a municipality (*2*). Payment is usually a flat annual amount, although it is feasible as an alternative to pay reimbursement of time and material. The owning agency retains control of the design of the phasing, and the maintaining agency is authorized to adjust the timing.

The Montgomery County, Maryland, Division of Traffic Engineering maintains all traffic signals on state roads in the county for the state. The details of the cost items comprising the annual charge to the state are given in Chapter 6.

In a related arrangement, a small local government may perform routine inspection and straightforward field maintenance, and contract with another jurisdiction for technical assistance. *Synthesis 22* noted that "in one state, small municipalities and rural counties may take advantage of the state highway department's central signal shop for any bench work required or for help in diagnosing signal malfunctions" (*2*). This service may be free of charge, or paid for as a flat amount, or reimbursed on the basis of time and materials.

The second type of maintenance contract is with a public utility or an electrical contractor. Maintenance by a public utility is much more common for lighting than for signals. A maintenance contract can be limited to include only those tasks that are well defined, such as group relamping, painting, and bench repair. Where new installations are constructed by outside contractors, a period of contract maintenance may be a part of the installation contract (*2*).

The author of the present synthesis report has testified as an expert witness in several accident cases in which the signals were maintained by public utilities through long-term contracts that had been in effect for many years. Based on this experience he believes that a local government contemplating entering into such a contract, or renewing an existing contract, should look closely into the utility's attitude toward the signal work. If the utility's mission is the provision and distribution of power, will its administrative and technical personnel feel much motivation to maintain signals as a sideline? Or will the signals be a "stepchild" that the utility just does not care much about? As in other endeavors in life, attitude can make the difference between success and failure.

Noncomputer-Based Equipment

The report for PennDOT (*13*) assists the small municipality in deciding whether contract maintenance of conventional equipment is cheaper than hiring one's own forces. It is derived in Chapter 6 that one signal mechanic can maintain 34 intersections under the assumptions considered appropriate for Pennsylvania. If that mechanic earns $22,400 per year, including fringe benefits, and requires $50,000 of initial equipment cost (which can be spread over 5 years), then the yearly expense to maintain 34 intersections is $32,400. This is the required annual maintenance budget for a small local government considering performing its own maintenance.

If this work were contracted out, at an assumed contractor rate of $30 per hour, then the $32,400 budget would buy 1,080 hours of service. The report for PennDOT (*13*) concluded that preventive and response maintenance will total 48 hours per intersection per year, so the budget will allow $1080 \div 48 = 22$ intersections to be serviced by the contractor. The report concludes that if the number of intersections is greater than 22 it may be to a municipality's advantage to maintain these signals.

The Indiana Department of Highways places primary emphasis on using state personnel to maintain all traffic control devices on the state system (*64*). Where state personnel are not available, the second choice is that the work be done by cities under a negotiated agreement that establishes the work to be done and the unit prices. The third method available is to use private contractors; this has been done in varying degrees for many years, originally because unions promoted the use of unionized labor to work on public electrical equipment. Indiana has found maintenance contracts on both lighting and signals to be the most cost-effective and practical method in high-density areas.

Indiana contracts call for both routine and emergency maintenance, and have been priced by competitive bidding since the mid-1970s.

> These contracts had a relatively small number of bid items, such as labor, equipment, and routine maintenance, and did not require or receive positive on-site inspection and documentation. The auditors, therefore, suggested modifications of future contracts to permit the use of work items which would be measurable and identifiable and would permit positive inspection and verification of units of work having been done. This reworking of the contract bid items has been used on the large maintenance contracts in Indianapolis and Marion County.
>
> The level of preventive maintenance and inspections was also decreased to what is considered to be an acceptable and practical level, and which appears to be more economical. This has resulted in a lowering of the contract bid price by 31 percent. The change of items also resulted in a large increase in the number of items required to pay for the major work items involved in the maintenance of traffic signals, and the need to establish prices reflecting work done during overtime and double time hours, as well as regular working hours (*64*).

Indiana has found the average cost per intersection per year to be approximately $1,000 for traffic signals and $550 for flashing beacons.

The New York State DOT, also, has concluded that contract maintenance is cost-effective in high-density areas. In 1981 an average cost of $1,000 per intersection covered everything except knockdowns and the cost of electric power. However, in high-density areas where competition among contractors is intense, and a contractor is already established nearby, the bid prices recently have been $720 for straight maintenance plus $110 to relamp each signal once per year, for a total of $830 (D. Russo, personal communication, 1982).

Maryland has three area-wide construction contracts that are bid annually for the eastern, central, and western portions of the state. Three different contractors are involved and merely through the issuance of a work order they can be instructed to respond immediately in the performance of maintenance and construction activities at existing traffic signals. These contracts are not intended for new construction; however, they could be. They are intended for providing maintenance at existing traffic signals because of the lack of adequate manpower within the state agency and because of the need for quick emergency response.

Three different levels of work urgency are set forth in Maryland contracts. The routine work is required to be done within 30 days of the issuance of the work order. High priority work is required to be accomplished within 7 days, and emergency work is required to be accomplished within 48 hours. The three types of work are paid for at the rates of 100%, 125%, and 150%, respectively, of the unit prices bid by the contractor for the various types of work set forth in the special provisions. Maryland has found these contracts to be extremely helpful in providing needed traffic-signal maintenance work in a minimum amount of time and at a relatively low cost.

Similar to the annual area-wide maintenance and construction contracts, Maryland also has an area-wide contract for system engineering review and analysis. This latter contract involves traffic engineering review and analysis of existing traffic signal systems for (a) ensuring that the systems are operating as intended and as timed, and (b) recommending new timing and operational strategies. The contractor involved in this work is not responsible for equipment repair. However, the contract does call for the contractor's identification of malfunctioning traffic signal components, and the reporting of these in a timely fashion for repair by State Highway Administration staff (T. Hicks, personal communication, 1984).

Computer-Based Systems

As a minimum, contractor support is required for computer maintenance because of the spares and skills required. Often, maintenance of the peripheral devices and the software is contracted out as well. Another type of maintenance that can be performed by non-city forces is the repair of electronic multiplexing modules used for sophisticated communications.

The FHWA's *Traffic Control Systems Handbook* (*5*) explains very well the difficulties of coordinating the maintenance function, and the choice between coordination by the city versus coordination by a systems manager:

> Computer systems, in particular, have introduced the traffic control field to the case where multiple agencies are involved in the system maintenance program, thus requiring endless coordination. Computers are maintained by vendor contract; communications systems may involve leased facilities and telephone company maintenance policies; while field hardware may involve multiple contractors or varying levels of in-house skills. All of these factors demand a high level of coordination. At best, the maintenance situation represents a challenge to teamwork and management ability. At worst, extreme frustration and unsatisfactory system operation can be the result.
>
> The procedure utilized by the UTCS project in Washington, D.C., illustrates the complexity of factors to be considered and the interrelationship of agencies involved in the maintenance program. As indicated by [Figure 22] a systems manager has been retained, by contract, to be the agent primarily responsible for total maintenance. Individual maintenance elements have then been further assigned to the computer manufacturer, telephone company, D.C. Department of Traffic, area transit authority, and other subcontractors. For cities choosing to coordinate their own maintenance program, substituting the appropriate city department's name in those blocks labelled as systems manager on [Figure 22] would represent a typical organization (*5*).

The FHWA's *Management of Traffic Control Systems* notebook (*65*) cites Omaha's approach, where the initial system bid included an item for system maintenance specified as follows:

- Bench repair of field equipment (detectors, communications, and controller interface units).
- Spares inventory.
- Scheduled and emergency maintenance of central equipment.

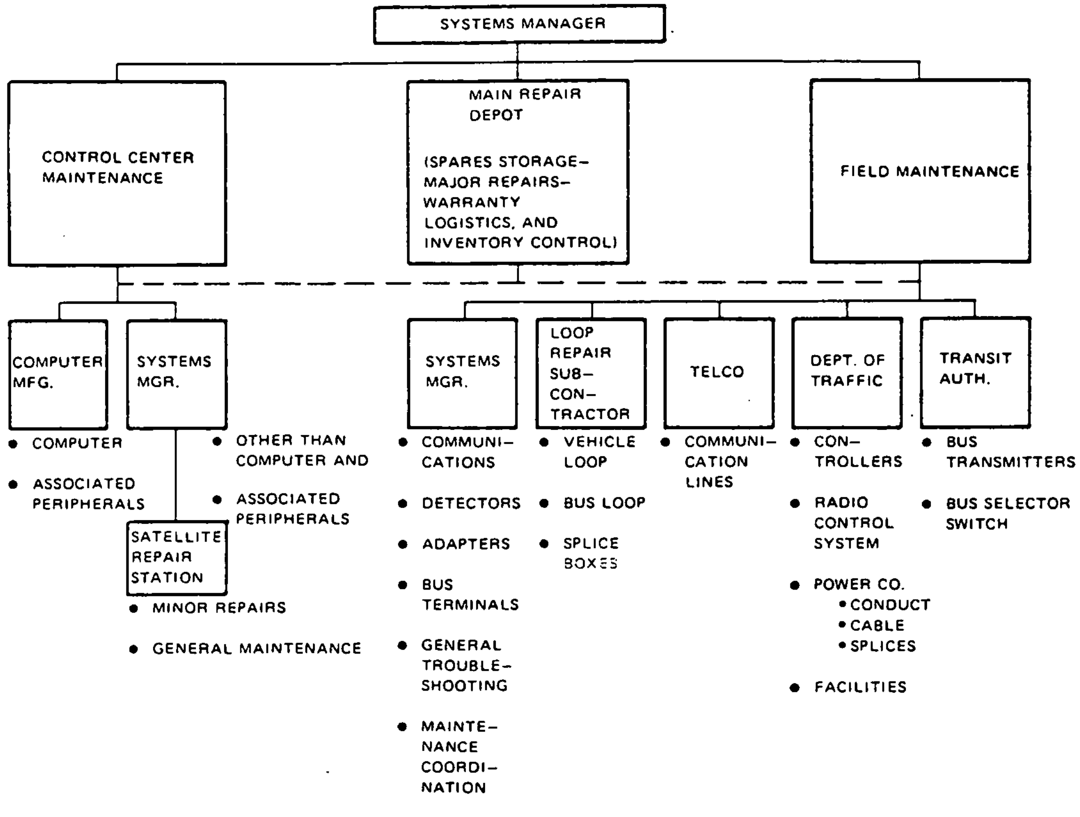


FIGURE 22 Diagram of UTCS maintenance responsibilities, Washington, D.C. (*5*).

The contract was for a five-year period with the initial year's price bid as a lump sum. The price for the four subsequent years is to be the initial bid price adjusted by the Consumer Price Index (CPI). In this way the City established a long-term commitment with the system supplier at a fixed price. They further feel that they have realized subtle benefits in system reliability by this approach to maintenance.

Chapter 2 contained a section on the maintenance of central control equipment, including both hardware and software. That section supplied some information on contractor support for computer-based systems. For example, it referenced Bigelow's *Guide to Negotiating a Computer Contract (42)*.

CHAPTER SIX

MAINTENANCE COSTS AND FUNDING

The frequency and cost of the maintenance of various controller/detector configurations depend on many factors, including the following:

- Type of equipment and detection
  Electromechanical, discrete solid state, microprocessor, etc.
  Magnetic detectors, long quadruple loops, etc.
- Degree of stringency of the purchaser's specifications
- Quality of components
- Quality control during assembly of component by the manufacturer
- Quality control during the installation work
- Degree of stringency of the purchaser's acceptance-testing program
- Severity of the environmental conditions in which the equipment and loops must operate
- Extent to which the agency is aware of malfunctions, through inspection programs, self detection, etc.
- Quality of the repair work once a malfunction is discovered

Inasmuch as these factors vary widely from jurisdiction to jurisdiction, it is not surprising that the call rates and dollar costs, for example (cited in this chapter from various sources), exhibit a range of values. It is apparent that each agency has the opportunity to influence many of these factors—particularly specifications, inspection, and acceptance testing—in an effort to reduce the maintenance burden.

ESTIMATES OF CALL RATES, WORK UNITS, AND PERSON-HOURS

Data are now available on annual call rates for preventive and response maintenance, work units required to maintain various devices, and person-hours needed.

Call Rates

Table 4 shows data provided by JHK & Associates (B. S. Marrus, personal communication, 1983) on rates of trouble calls and total calls for eight cities and one state highway department. A simple, unweighted average shows about nine calls per signal per year for all maintenance purposes, two-thirds of which are in response to a malfunction. These calls would be for any and all equipment in the cabinet or in the signal heads, presumably.

TABLE 4

COMPARISON OF MAINTENANCE-CALL RATES IN NINE WESTERN JURISDICTIONS (B. S. Marrus, personal communication, 1983)

City	No. of Signals	Avg. Annual Call Rate[a]	Avg. Trouble Call Rate[b]
Tempe, Arizona	85	18.50	11.83
Boise, Idaho	168	10.52	8.95
Reno, Nevada	155	9.52	8.52
Scottsdale, Arizona	93	5.10	5.10
Springfield, Oregon	31	8.74	4.77
Lane County, Oregon	25	10.36	4.60
OSHD	14	7.55	4.50
Eugene, Oregon	150	8.38	4.44
Salt Lake City, Utah	136	5.25	2.21
Average	95	9.32	6.10

[a] Average number of total maintenance calls per signal per year.
[b] Average number of nonscheduled maintenance calls.

Data on call rates for controllers only was gathered by the New York State DOT, for the first six months of 1982, in the most densely populated countries of the Albany region (*29*). The results, shown in Table 5, indicate that modern, digital controllers require about one service call per year. The NYSDOT commented that, although the comparison sample between the Model 170 and the solid-state/digital-timed controllers is small, they are not surprised that the call rates are similar. "Since the worst solid-state units are replaced with 170s as the former fail, it is only natural that the best-performing solid state units would still be left" (D. J. Russo, personal communication, 1982).

The NYSDOT estimates that their 170s each require about six calls per year for all causes except relamping. Of the six, one is for the controller, one for the load switches, and four are for detectors. This rate of detector calls is higher than the

TABLE 5

CONTROLLER-ONLY MAINTENANCE CALLS IN SIX MONTHS IN 1982 IN AN AREA OF NEW YORK STATE (*29*)

Controller Type	Signals	Calls	Calls/Type (6 months)
Electro-mechanical			
Semi-actuated	58	32	0.55
Full actuated	9	9	1.00
Volume-density	9	7	0.78
Solid State/Analog Timing (Semi-actuated)			
2 phase	10	1	0.10
Solid State/Digital Timing (Full actuated)			
2 to 4 phase	84	35	0.42
5 to 8 phase	14	7	0.50
Model 170 Microprocessor			
All	59	29	0.49
Total	243	120	0.49

average in that jurisidiction, and is due to the fact that detector failures are well monitored in the 170 design. If a detector fails by not calling, or constant calling, over a specified period of time, a light on the top of the cabinet is automatically illuminated, alerting passing police and traffic-engineering personnel.

The data in Table 5 show a marked improvement over the NYSDOT call rates reported by Parsonson and Tarnoff (*29*) for a one-year period in 1976 and 1977, before any 170s had been installed. The comparable data from that one-year period are shown in Table 6.

Parsonson and Tarnoff also reported call rates experienced by the Ohio DOT, the Minneapolis District of the Minnesota Department of Highways, Cincinnati (Ohio), Tampa (Florida), Charlotte (North Carolina), Springfield (Illinois), and Winston-Salem (North Carolina). The 67 microprocessor controllers in Charlotte were reported to require 0.99 calls per signal per year. This rate is almost identical to that reported in Table 5 for New York's Model 170 controllers, which of course are also microprocessor-based.

TABLE 6

PORTION OF NYSDOT CONTROLLER FIELD-MAINTENANCE DATA FOR A ONE-YEAR PERIOD BETWEEN 1976 AND 1977 (*29*)

Controller Type	Signals	Calls	Calls/Type (1 year)
Electro-mechanical			
Semi-actuated	583	1520	2.61
Full actuated	251	994	3.96
Volume-density	24	115	4.79
Solid State/Analog Timing (Semi-actuated)			
2 phase	28	27	0.96
Solid State/Digital Timing (Full actuated)			
2 to 4 phase	37	54	1.46
5 to 8 phase	14	58	4.14
Model 170 Microprocessor			
All	None	-	-
Total	937	2768	2.95

Caltrans Districts 3 and 5 have recently conducted a study (K. McDaniel, personal communication, 1983) of the reliability of their Model 170 controllers. Excluding load switches and detectors from their data, they determined a mean time between failures of seven years, corresponding to 0.14 calls per year. They believe that this excellent record is due to their stringent acceptance-testing program. California and New York (and also Oregon) currently perform acceptance tests on all Model 170 controllers on arrival from the factories, at a cost of $500 to $600 per unit. They experienced a rejection rate of 50 percent during the late 1970s. During the period from 1981 to 1983 the rejection rate gradually dropped to about 20 percent.

In a similar program, Oregon tested equipment built to NEMA standards at a cost ranging from $800 to $1,100. The rejection rate was 90 percent. California also tested non-170 controllers and rejected 98 percent of them (*51*).

Call-rate data for electromechanical pretimed controllers appear to be close to 1.8 per year, according to data from NYSDOT and the City of Cincinnati, as reported by Parsonson and Tarnoff (*29*).

A total of 497 loop detectors were installed as a part of the Urban Traffic Control System Research Project sponsored by the Federal Highway Administration. The installations were made (around 1970) only after a thorough study by the contractor of the available (crystal) electronics units and the procedures and materials for installing the loop wire and lead-in. In the first year there were 33 failures of the electronics units, for an annual rate of 0.07 failures/detector. During that period 26 loops failed because of utility excavations; if these failures are added the total annual rate becomes 0.13 failures/detector (*29*). (See Chapter 7 for calculations of mean time between failures for the various components of a central digital system.)

Maintenance Work Units

In 1977, Stout et al. (*50*) presented guideline maintenance work units for the range of equipment that would normally be encountered in a traffic-control system. Their guideline is reproduced herein as Table 7. They explained that these units are a relative indicator of the difficulty and time required to maintain various items of equipment.

The guideline is to be used by first summing the work unit values for an existing system that is being considered for improvement. If the existing system has a summed work unit value of 1000, for example, and is known to require two maintenance personnel, then an alternative with a work unit value of approximately 2000 would be expected to require four maintenance personnel.

Person-Hours

Parsonson and Tarnoff (*29*) reported the work hours required for the field maintenance (only) for selected NYSDOT con-

TABLE 7

GUIDELINE EQUIPMENT MAINTENANCE WORK UNITS (*50*)

Device	Maintenance Units[a]
Fixed-Time Controllers	
Single Dial	5
Three Dial	8
Actuated Controllers	
Two-Phase (all)	11
Three-Phase (all)	13
Four-Phase (solid state)	17
Five-Phase (solid state)	21
Six-Phase (solid state)	27
Eight-Phase (solid state)	31
Five-Phase (electromechanical)	27
Eight-Phase (electromechanical)	41
Electromechanical Coordination Device	7
Electronic Coordination Device	10
Controller Modification and Communication Device	
FDM	5
TDM or FSK	7
Fixed-Time Master	11
Analog Master - Simple	24
Analog Master - Complex (or any digital master)	48
Vehicle Detector	7
Cable - up to 12 pair (or conductor) per mile	5
Add for each 12 pair per mile	1
Leased Telephone Line (per line)	5
Computer Facility (with maintenance contract)	100-300
Microprocessor	25

[a] Maintenance work units are a relative indicator of the difficulty and the time required to maintain various items of equipment. No direct conversion to person-hours or dollars are provided.

trollers and detectors for a one-year period from 1976 to 1977. Their data are reproduced herein as Table 8.

Their data can be compared with that prepared for PennDOT in 1982 (*13*). That report determined for various intersection complexities the annual hours of working time needed for preventive maintenance. They assumed maintenance level A (rather than the minimum of B, as explained earlier) but omitted the time-consuming tasks of repainting cabinet, signal heads, mast arms, and poles every two to five years. Also, they added travel time at a rate of 1 hour for every 6.5 hours of working time. Table 9 shows that the results vary from 18 to 68 hours. However, cases I, IV, and V are the most common and average 36 hours, a level recommended in the report to be used as typical.

The PennDOT report cited data obtained from a maintenance questionnaire to conclude that, on the average, the total time per intersection for preventive and response maintenance combined is 48 hours per year. This estimate appears reasonable when compared with the average of 26 hours for field maintenance only shown in Table 8 for NYSDOT intersections.

NUMBER OF PERSONNEL NEEDED

The report for PennDOT estimated that the annual productive work hours amounts to 1,627 (assuming a 40-hour week and deducting 3 weeks for vacation, 2 for sick leave, 1 for training courses, 13 legal holidays and 30 minutes per day for coffee

TABLE 8

ESTIMATED FIELD-MAINTENANCE DATA FOR SELECTED NYSDOT CONTROLLERS AND DETECTORS FOR A ONE-YEAR PERIOD BETWEEN 1976 AND 1977 (*29*)

Controller Type	Signals	Calls	Total Work Hours	Work Hours per Signal
Electromechanical				
Pretimed	84	154	646	7.69
Semi-actuated	583	2,874	10,781	18.49
Fully actuated	251	2,385	9,504	37.86
Volume-density	24	245	914	38.08
Mixed Electromechanical and Solid State				
Semi-actuated	473	2,132	9,626	20.35
Fully actuated	194	1,820	7,461	38.46
Solid State, Analog Timing				
Semi-actuated	28	95	491	17.54
Fully actuated				
2-4 phase	72	687	2,829	39.29
5-8 phase	22	366	1,411	64.14
Solid State, Digital Timing				
Fully actuated				
2-4 phase	37	259	1,141	30.84
5-8 phase	14	188	829	59.21
Total	1,782	11,190	45,633	25.61

breaks). Dividing the annual 48 hours to maintain an intersection into the 1,627 annual productive work hours resulted in an estimate of 34 intersections that can be maintained by one mechanic.

This estimated ratio of 34 intersections/mechanic can be compared with known ratios in a number of cities. Table 10 shows staffing data gathered by JHK & Associates in 25 cities across the United States. The average ratio is 39 signals/mechanic. There is no information as to whether the maintenance levels are adequate in these cities; that is, for all we know some

TABLE 9

TIME ESTIMATES FOR PREVENTIVE MAINTENANCE OF INTERSECTIONS OF VARIOUS COMPLEXITIES (*13*)

Intersection Type	Annual Person-Hours
Case I: Two-phase, semi-actuated, electromechanical, 12 signal heads	41
Case II: Two-phase, pretimed, electromechanical, one signal head in center of intersection (not conforming to the MUTCD)	18
Case III: Eight-phase, fully actuated, solid state, volume-density, 28 signal heads (incl. 8 for pedestrians)	68
Case IV: Two-phase, pretimed, electromechanical, 12 signal heads	31
Case V: Two-phase, semi-actuated, solid state, 12 signal heads	34

TABLE 10

MAINTENANCE STAFFING IN 25 U.S. CITIES (B. S. Marrus, personal communication, 1983)

City	Total No. of Signals	Signals Controlled by Computer	Maintenance Staff No.	Ratio[a]
Columbus, Ohio	746	94	10	74.6
Scottsdale, Arizona	93	27	7	13.3
San Diego, Calif.	760	250	14	54.3
Reno, Nevada	155	103	5	31.0
Seattle, Washington	704	-	25	28.2
Fort Worth, Texas	407	85	13	31.3
Kansas City, Mo.	595	-	15	39.7
Chattanooga, Tenn.	179	79	8	22.4
Indianapolis, Ind.	650	-	8	81.3
Boise, Idaho	168	104	5	33.6
Mesa, Arizona	133	-	7	19.0
Tempe, Arizona	85	-	2	42.5
Portland, Oregon	856	227	13	65.8
Salt Lake City, Utah	179	168	5	35.8
Greensboro, N. C.	240	208	10	24.0
Phoenix, Arizona	535	320	11	48.6
Amarillo, Texas	220	136	7	31.4
St. Louis, Missouri	560	0	10	56.0
Minneapolis, Minn.	737	665	14	52.6
Milwaukee, Wisconsin	720	b	27	26.7
Atlanta, Georgia	800	b	16	50.0
Cincinnati, Ohio	687	b	24	28.6
Arlington, Virginia	214	b	10	21.4
Tucson, Arizona	220	125	8	27.5
Alexandria, Virginia	220	b	5	44.0
Average ratio				39.0

[a]Number of signals per staff member.

[b]Data not available.

of these cities could be significantly understaffed. Furthermore, there may be some error in the data; Atlanta, for example, actually is known to have 32 maintenance staff, not the 16 shown, therefore the correct ratio is 25 signals/mechanic. Finally, there needs to be an accounting of whether the maintenance staff also installs new signals. (In Atlanta the 32 do not perform construction duties.)

Fulton County, in the Atlanta area, recently (in 1983) performed calculations similar to those of PennDOT to arrive at an estimate of a desirable staffing level (C. F. Conway, personal communication, 1983). The complexity of the average Fulton County intersection indicates 44 hours per year for preventive maintenance. Increasing this by one-third to consider response maintenance gives a total of 58 hours per year. The annual productive time of an employee is only 1540 hours (because of a 37.5-hour work week); therefore, only 26 intersections can be maintained by one employee.

TABLE 11

MAINTENANCE STAFFING IN THREE LOCAL GOVERNMENTS IN THE ATLANTA AREA (E. F. Conway, personal communication, 1983)

Local Government	Total No. of Signals	Maintenance Staff No.	Ratio
City of Atlanta	800	32	25.0
DeKalb County	680	27	25.2
Clayton County	87	3	29.0

Fulton County made a survey of three other local governments in the Atlanta area and found that the number of signals per nonclerical employee is about 25, as shown in Table 11.

The City of Los Angeles has a staff of 61 electricians to service 3,669 signals, for a ratio of 60 signals per electrician (*44*).

MAINTENANCE COSTS

An earlier section entitled Contract Maintenance quoted some maintenance costs reported by the Indiana Department of Highways and the New York State DOT.

When the maintenance is performed by the NYSDOT's own forces, the overall costs have recently (1982) been determined as follows:

> Using personal-service costs (regular plus overtime) and maintenance material costs, our average cost to maintain each signal, which can range in complexity from warning sign beacons to eight-phase interaction control, is $479, not including energy (D. J. Russo, personal communication, 1982).

Parsonson and Tarnoff (*29*) merged data from the Caltrans Maintenance Management System and NYSDOT files to determine the total annual cost to maintain various types of traffic signals in 1977. The results are shown in Table 12. These costs include field and bench work, parts, and travel for all of the scheduled and unscheduled maintenance of all electrical equip-

TABLE 12

PROJECT-STAFF CONCLUSIONS FOR THE TOTAL ANNUAL COST TO MAINTAIN VARIOUS TYPES OF TRAFFIC SIGNALS (*29*)

Controller Type	Cost per Signal for Various Phasings ($)			
	2 phase	3-4 phase	5-8 phase	All
Electromechanical				
Pretimed	-	-	-	115(D)[a]
Semi-actuated	291(D)	-	-	-
Full actuated	508(D)	753(C)	1209(C)	-
Volume-density	613(D)	1162(C)	1506(C)	-
Solid State, Analog Timing				
Semi-actuated	258(D)	-	-	-
Full actuated	532(D)	657(C)	1610(C)	-
Solid State, Digital Timing				
Full actuated	575(C)	661(C)	1091(C)	-
Microprocessor				
Full actuated	-	421(C)[b]	757(C)[b]	-

[a](C) = Cost taken from Caltrans maintenance management system data. (D) = derived.

[b]These data are for a few controllers from a single manufacturer. Other microprocessor controllers may have different maintenance requirements.

ment at the location, including lampouts, detector malfunctions, and knockdowns. (Lampouts should be negligible in these statistics because of a group relamping program.)

In June of 1983 the California DOT completed a six-month pilot study of the cost to repair Model 170 microprocessor-based controllers at their central repair facility in Los Angeles. Over six months the total of 1,757 controller units in service required $52,476 in repair costs, for an average of $30 per unit. This amounts to $60 per year (K. McDaniel, personal communication, 1983). Table 13 summarizes the six-month study.

In 1977 Stanford and Parker (*66*) reported the cost to operate and maintain the 112 signals of the South Bay computer-controlled system in Los Angeles County. The monthly cost to maintain the field equipment amounted to $4,000, and the computer and peripherals were maintained by contract at a cost of $2,100 per month. Stanford and Parker commented as follows:

> In-house capability for repair of field hardware had to be developed within the constraints of existing staffing. An extensive period of time was required for traffic signal technicians to become competent in repairing the new and unfamiliar equipment. Circuit board repair was frequently a bottleneck. Experience revealed the necessity for a large inventory of spares and a well equipped repair facility. Two full-time maintenance technicians are needed to support a system of this size. With increased productivity from increased expertise, some reduction in staffing in this area may be possible.

The City of Los Angeles maintains 3,669 signalized intersections, about half of which have fixed-time controllers; the other half have semi-actuated controllers. Most are interconnected in hard-wired systems. In 1981-1982 their expenditures on signal maintenance were as follows (*44*):

Labor	$1,731,000	(direct labor only, no overhead)
Materials	1,486,000	
Equipment	249,000	
Total	$3,466,000	
Electricity	2,575,000	
Telephone Line Lease	107,600	

Total maintenance costs were about $945/yr/signal with electricity adding another $702/yr/signal.

In Maryland, the Montgomery County Division of Traffic Engineering maintains all traffic signals on state roads in the county for the state. The county itemizes its costs and makes an annual charge to the state for this maintenance (R. C. Welke, personal communication, 1983). For fiscal year 1984 the charge for the 412 signals maintained by the county is estimated to be $1,100/yr/traffic signal. This does not include energy costs or engineering costs that are incurred in the process. (The electrical energy cost for the typical traffic signal in FY 1982 was more than $1000.) The estimated maintenance charge for FY 1984 was itemized as shown in Figure 23.

COST-EFFECTIVENESS OF ADEQUATE MAINTENANCE

Table 12 shows that the annual cost to maintain various types of traffic signals can range from $115 to $1610. This should be compared with the dollar penalty to motorists when malfunctioning signals increase their stops and delay.

For example, for an intersection with a combined volume of 10,000 vehicles per day and approach speeds of 35 mph, it can be shown from various sources in the literature that the cost of stopping a typical mix of cars and trucks is $44.50 per 1000 stops as of 1983. Similarly, it can be derived that the value of motorist time for this mix is $6.65 per hour, and the cost of fuel consumed while idling the vehicle is close to $1.00 per hour. Thus, the total delay cost is $7.75 per hour.

Using these traffic volumes and costs of stops and delay, the annual benefits that would accrue for each percent reduction in stops and each second of reduction in average delay can be calculated to be $1,624 and $7,855, respectively.

These figures illustrate how signal malfunctions that increase stops and delay by just a small amount can cause costs to motorists that far exceed the costs to maintain the signals properly.

TABLE 13

SUMMARY OF COST TO REPAIR MODEL 170 CONTROLLERS IN CALIFORNIA BY MANUFACTURER (K. McDaniel, personal communication, 1983)

Manufacturer	Total Failures	Total Units	Total Hours	Average Hours/Repair	Maximum Hours	Total Cost	Average Cost/Repair
A	316	703	1,498.50	4.75	61.00	20,951.18	66.31
B	15	48	76.50	5.10	15.00	938.05	62.54
C-1	3	6	9.00	3.00	4.00	111.46	37.16
D	17	22	55.00	3.24	7.00	800.39	47.09
E	241	480	873.50	3.63	24.00	12,295.75	51.02
F	174	322	755.50	4.35	48.00	11,127.33	63.96
G	6	9	77.50	12.92	56.00	1,079.91	179.99
C-2	47	126	204.50	4.36	20.00	2,936.56	62.48
C-3	30	41	158.50	5.29	12.00	2,235.24	74.51
Totals	849	1,757	3,708.50			52,475.87	

SALARIES

Regular Pay

Title	Annual Salary	X	Persons in Position	X	Maintenance Time (%)	=	Subtotal
Supervisor, Signal Unit	$ 35,540		1		50		$ 17,740
Sig. Tech. II	29,474		1		100		29,474
Sig. Tech. II	29,474		1		40		11,789
Sig. Tech. I	23,247		6		100		139,482
Sig. Tech. I	23,247		2		40		18,597
Equip. Oper. I	20,255		1		60		12,153
Pub. Ser. Work. II	16,440		1		40		6,576
							235,811
	Fringe benefits at 27.5% of regular salary					=	64,848
	Total regular salary					=	$ 300,659

Overtime Pay

Overtime rate for Signal Tech. I:

$23,247/yr ÷ 2080 hr/yr = $11.17/hr regular rate

$11.17 + 50% = $16.75 overtime rate

Average overtime per week for emergency signal maintenance by Traffic Signal Technician I is 13 hours.

Total overtime:

13 hr/wk X 52 wk/yr X $16.75/hr	=	11,323
Total Salaries	=	$ 311,982

VEHICLE COSTS

Flat Rate Charges:		
4 vans X $140/mo/vehicle X 12 mo	=	$ 6,720
1 bucket truck X $1,570/mo X 12 mo	=	18,840
Mileage Charges:		
4 vans X 13,764 mile/vehicle X $0.24/mile	=	13,213
Total vehicle costs	=	$ 38,773

MATERIALS

Traffic Signal Parts	=	$ 86,770
Supplies and Maintenance Materials	=	14,670
Total material costs	=	$ 101,440

SUMMARY

Salaries	$311,982
Vehicle Charges	38,773
Materials	101,440
Total	$452,195

PER INTERSECTION COSTS

Assume that 15 signals are added per year.

In FY '84 there will be 382 + 30 = 412 signals maintained by the county.

$452,195 ÷ 412 = $1,097 average cost per intersection.

Thus the FY '84 estimated cost per intersection will be $1,100/yr.

FIGURE 23 Estimated maintenance cost per traffic signal for fiscal year 1984 (Montgomery County, Maryland).

CHAPTER SEVEN

MANAGEMENT CONTROL

Adequate maintenance of traffic signals requires a major expenditure of manpower, material, and funds. This requires a high degree of management control, which can be broken down into the components of technical control, material control, administrative control, fiscal controls, contract maintenance management, and the administration of equipment replacement programs.

TECHNICAL CONTROL

The FHWA's *Management of Traffic Control Systems* Notebook (*65*) points out that maintenance ought to be considered early in system design. Using Figure 24 the Notebook illustrates that trade-off analyses can lead to a proper balance between first cost on the one hand and recurring maintenance expense on the other. "Two factors which can enhance system maintainability are standardization of components and modularity" (*65*).

Equipment-Evaluation Considerations Affecting Maintenance

The characteristics that should be considered in the selection of an equipment alternative were set forth by Cimento in 1980 (*39*). Fully half of these characteristics pertain directly to maintenance, as follows:

- *Reliability:* This is a function of the equipment-engineering design. It describes the designed-in ability of the equipment to maintain its functional integrity and continue to perform without failure or degradation.
- *Maintainability:* An equipment requiring simple maintenance procedures would receive a higher score for this attribute than one that requires specially trained personnel, special test equipment, or frequent preventive maintenance.

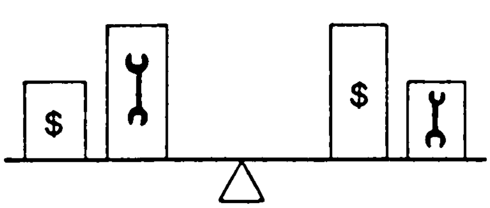


FIGURE 24 Graphic representation of design consideration (*65*).

TABLE 14

RATINGS OF CONTROLLER SUBSYSTEMS[a]

Criterion	Controller Type: Solid State Actuated	Solid State Pretimed	Electro-mechanical Pretimed	Micro-processor (170 type)
Reliability	F[b]	G	F	G
Maintainability	F	F	G	F
Damage Resistance	NSS[c]	NSS	G	NSS
Monitoring Capability	G	G	F	G

[a]Adapted from Reference 39.
[b]F = fair; G = good.
[c]Noise and surge susceptible.

- *Damage Resistance:* This is the equipment's ability to avoid malfunction from causes not related to design; examples are vandalism, hostile physical environment, or rough handling.
- *Monitoring Capability:* This is a measure of how well an equipment can be kept under surveillance for malfunction in performance.

Cimento rated the currently used alternative equipment for each of the major subsystems according to these criteria, as shown in Tables 14 to 17.

TABLE 15

RATINGS OF DETECTION AND SURVEILLANCE SUBSYSTEMS[a]

Criterion	Detection Type: Inductive Loop	Magnetometer
Reliability	G[b]	F
Maintainability	G	F
Damage Resistance	G	G
Monitoring Capability	G	F

[a]Adapted from Reference 39.
[b]F = fair; G = good.

TABLE 16

RATINGS OF COMMUNICATIONS SUBSYSTEMS (MULTIPAIR CABLE)[a]

Criterion	Communications Type TDM[b]	FDM[c]	DC Relay
Reliability	G[d]	G	G
Maintainability	F	G	G
Damage Resistance	G	G	G
Monitoring Capability	G	F	P

[a]Adapted from Reference 39.

[b]Time division multiplexing.

[c]Frequency division multiplexing.

[d]G = good; F = fair; P = poor.

Controller Subsystems

The four principal controller designs were rated according to the four characteristics that pertain to maintenance (Table 14). Electromechanical pretimed controllers are low in cost, simple to maintain, and easy to adapt to an existing system. However, they are rated fair in reliability because parts-wear requires regular maintenance. Solid-state actuated controllers have the advantage that NEMA standards have made maintenance and interchangeability easy. On the other hand, they are higher in cost and maintenance requires a moderate level of skill. Solid-state pretimed controllers offer solid-state reliability, but they cost more than their electromechanical equivalent and require a higher level of maintenance skill.

Detection and Surveillance Subsystems

Ratings of the two kinds of vehicle detectors used in modern computerized systems are given in Table 15. The inductive-loop detector (ILD) offers good performance and is reliable where street condition is good. Where pavement is deteriorating, loop wire can be protected from grounding and breakage by sheathing it with polyethylene tubing (*67*). Also, it can be used in various configurations. On the other hand, the ILD requires street installation, and loops are difficult to repair. Magnetometers offer lower installation cost and can be used with long lead-in. However, their detection zone is not well defined, so their monitoring capability is limited to vehicle counts rather than determinations of presence time and occupancy.

Scheck (*26*) made a telephone survey of maintenance personnel in some states and a few municipalities. "The general concerns among state traffic engineers is that detector circuits are the most common maintenance problem. Since cities have few installations that require detection, they have other maintenance problems."

Communications Subsystems

Table 16 gives a comparison of the three kinds of communications used in digital systems. Time-division multiplexing is more complex to service than the other two types, but offers more flexibility for monitoring special functions. The failure of master control equipment causes entire groups of intersections to fail, whereas frequency division multiplexing minimizes the number of intersections lost. DC relays are reliable and easy to maintain but are poor in monitoring capability.

A recent survey by the Institute of Transportation Engineers identified communications as the single most troublesome element of the system. The problems related not only to hardware but also to difficulties with leased lines and the telephone companies.

Computer Subsystems

Table 17 was prepared for three different types of computer architecture. It shows the central-computer configuration rated only fair for reliability because the loss of the central computer requires standby control for all intersections. Distributed systems, by contrast, are insensitive to central-computer failure, but their arrangement in a number of curbside cabinets reduces their maintainability and makes them more susceptible to damage. They are not as well adapted to sending monitoring data to a central facility.

Summary

Several of Cimento's conclusions were presented in Chapter 2. He also found that the major sources of equipment problems seem to be the use of low-grade components (not suitable to the environment) and insufficient quality control.

TABLE 17

RATINGS OF COMPUTER SUBSYSTEMS[a]

Criterion	Computer Type Central	Hierarchical	Distributed
Reliability	F[b]	G	G
Maintainability	G	G	F
Damage Resistance	G	G	P
Monitoring Capability	G	G	F

[a]Adapted from Reference 39.

[b]G = good; F = fair; P = poor.

Design Features to Minimize Maintenance

Waight (*68*) explained a number of technical details showing how Caltrans "designs with maintenance in mind." California has an Electrical Specification Committee that spans a broad range of disciplines, resulting in what Waight feels are some of the best electrical specifications in the country.

Scheck (*26*) found in Ohio that one of the principal causes of failure of solid-state units appears to be power surges, such as those resulting from lightning striking close to the signal installation. The designer can attempt to minimize damage from

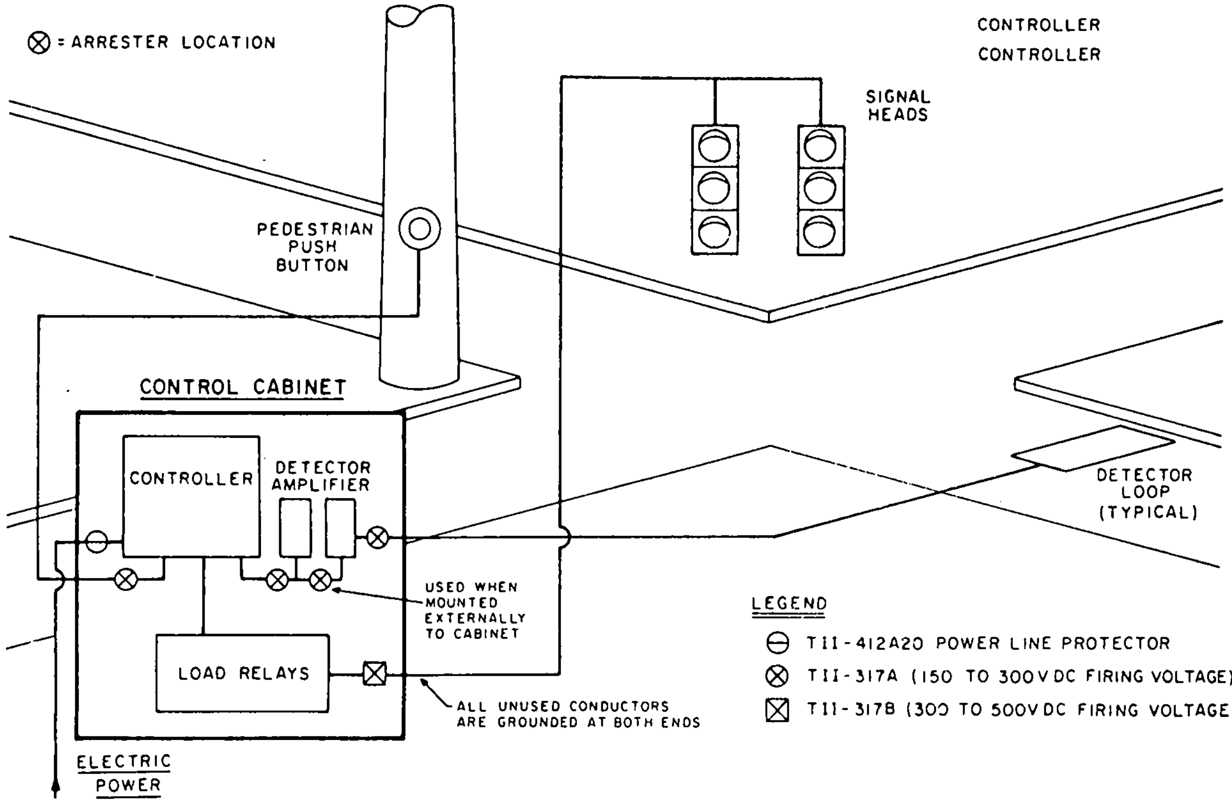


FIGURE 25 Schematic of typical intersection in Tampa (*70*).

voltage transients by specifying that controllers, detectors, and other equipment meet NEMA specifications for environmental requirements (*56*). Manufacturers use a variety of techniques to provide the required transient resistance. For example, one model of detector unit offers four different defenses to transients:

> Differential lightning protection is afforded by the four-element protective circuit composed of the input resistors, the neon tube, the transformer leakage inductance and the diode path across the secondary.
>
> Differential lightning-induced currents are also potentially damaging. These currents are shunted through the neon bulbs, limiting the voltage across the transformer. . . (*69*).

Tindale (*70*) found in the early 1970s that more than half the service calls were results of electrical surges.

> After trying and rejecting several ideas, our search brought us to the TII 3-Electrode Gas Tube Surge and Lightning Arrester. By installing these arresters at every wire pair that enters the controller [Figure 25], surges were trapped and junction damage prevented. The first-arriving surge spike ionizes the three-electrode gas tube and instantly grounds both wires, maintaining 20-volt maximum differential across the equipment until the surge is removed from both lines. In this manner, the first out-of-phase surge arrives at the three-electrode gas tube and ionizes the entire tube. This instantly grounds the surge and provides a path to ground for any currents in the second wire. As the second wire's surge arrives at the gas tube, it finds the electrode already grounded, effectively stopping the surge from flowing through the equipment [Figure 26].

Infurchia (*71*) provided details of stringent grounding and bonding to ensure a positive, low-resistance path for transients (see Figure 27).

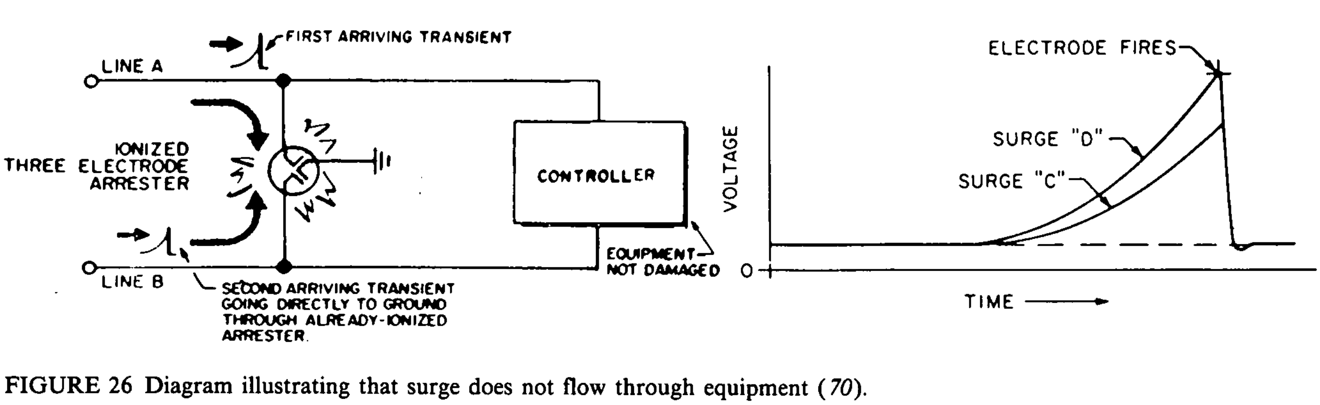


FIGURE 26 Diagram illustrating that surge does not flow through equipment (*70*).

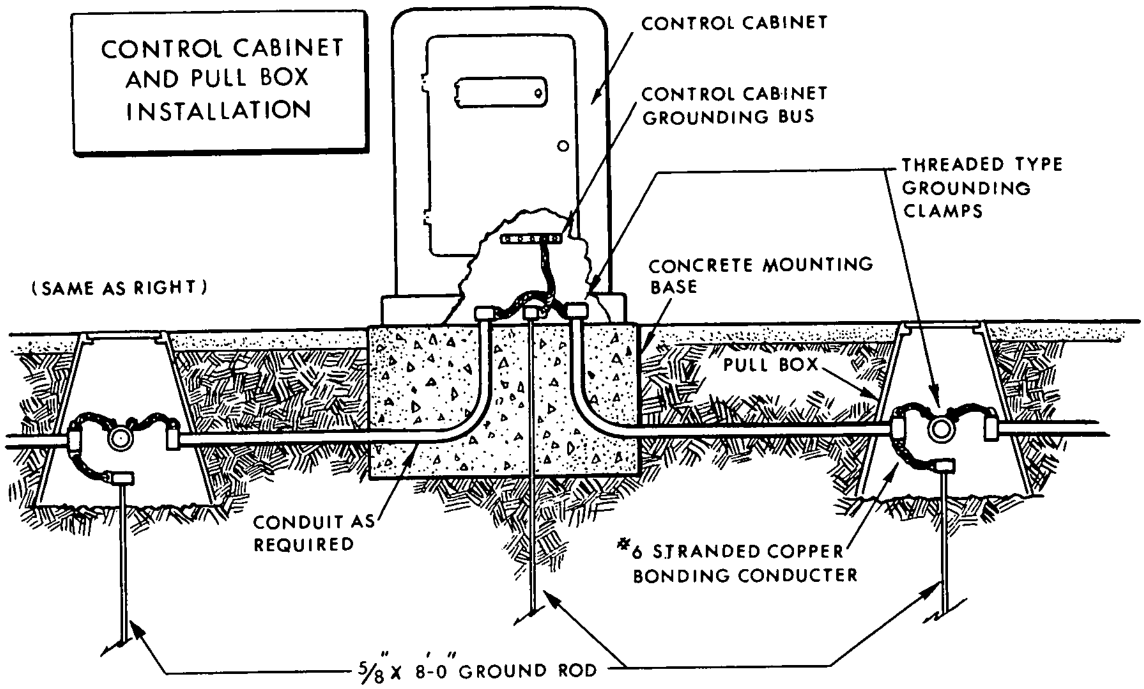


FIGURE 27 Cabinet-bonding technique (*71*).

The Arizona DOT no longer uses pedestal-mounted signals in medians because they concluded that pedestals, and poles on islands, are a safety problem. Many knock-downs in the middle of the night were causing injuries and damage as well as expensive overtime trips by repair crews. ADOT now uses mast arms 40 to 50 ft (12 to 15 m) long to mount their signals (*72*). They have also found that maintenance of pedestrian signals can become routine rather than "emergency" if the display is neon rather than incandescent. The latter type fails suddenly and completely, whereas neon fails by flickering for a long period before going out totally (*72*).

Reduced Maintenance through Tighter Procurement Specifications

Tighter procurement specifications obviously are important to reduced maintenance. The FHWA's *Traffic Control Systems Handbook* (*5*) emphasizes that "specifying components with higher reliability and demanding modularity of components are two ways either to reduce maintenance needs, or to make required maintenance easier to perform."

Stringent acceptance testing must go hand in hand with tight specifications. Waight (*68*) explained five purposes of the California DOT acceptance tests as follows:

> CALTRANS Standard Specifications require five days of successful functioning before a traffic signal is accepted. However, in addition, District 4 has an operational test performed on every controller assembly by our technicians in the district maintenance shop. This serves a number of purposes:
>
> a) It gives maintenance personnel the opportunity to become familiar with and to try out new traffic signal equipment in the friendly atmosphere of the shop rather than the unfriendly environs of an intersection.
>
> b) It permits the vendors to make repairs or corrections in the clean, dry conditions of a shop rather than outside.
>
> c) It eliminates the need for the public being the testing device for the five day test.
>
> d) It gives us the chance to correct defects that might have occurred in transit from our Materials and Research Laboratory—it's over 400 miles from Los Angeles to our shop.
>
> e) Finally, it gives the designer, who observes the operational test, an opportunity to look for design errors. Again, we find the shop a far better place than the intesection to discover and correct these design oversights (*68*).

Procurement specifications ought to include the requirement of good documentation of all aspects of the hardware and software.

Cost-Saving Strategies in Initial Procurements

Montgomery County, Maryland obtains spare parts for controllers and other control-cabinet equipment at lowest cost by buying on competitive bid all fully equipped eight-phase cabinets for new projects and setting aside the unused modules, load switches, and so on, as spares (W. S. Wainwright, personal communication, 1982).

Maryland has developed cost-saving strategies to reduce the bureaucratic processing of construction contracts, equipment procurement, personnel deployment, and the like (T. Hicks, personal communication, 1984). Through competitive bidding Maryland is able to secure long-term contracts for various components of traffic signal systems including equipment and material as well as engineering and construction services. This enables the state to go through the bidding process just one time and results in a contract from which equipment can be secured very quickly by a phone call and at an established price that holds throughout the life of the contract. These contracts can also run for a greater length of time (two years, three years, or longer). The contracts do have a tendency to lock the agency into one or two specific manufacturers. Such contracts may involve signal controllers, signal heads, signal poles and mast arms, vehicle detectors, etc.

Local jurisdictions in Maryland may buy from the state highway agency contracts and thus are able to secure needed equipment immediately and at an already established cost.

Other Strategies for Saving of Costs and Other Resources

States and counties, and perhaps some cities, may find it to their advantage to utilize the traffic engineering expertise and capabilities that are provided by other jurisdictions. This is particularly helpful to states where great distances are involved, wherein state-owned traffic signals may be maintained by the local jurisdiction's forces, who are readily at hand and are able to respond more quickly. Certainly, there are also efficiencies to be gained in allowing local jurisdictions to absorb certain state-owned traffic signal installations into local systems so that all signals operate in a compatible way to the benefit of the motoring public. The reverse might also be true—that is, adding local signals to state systems to provide efficient traffic flow (T. Hicks, personal communication, 1984).

Installation Procedures to Reduce and Expedite Maintenance

There are many examples of installation techniques and materials that can minimize maintenance and make it easier.

Waight noted that the Caltrans standards for controller cabinet location include six factors that relate directly to the technician, as follows:

> a) It should not be vulnerable to traffic—this protects the technician as well as the equipment.
> b) Traffic movements should be visible from the controller timing position.
> c) The cabinet door should be on the side away from traffic.
> d) It should not be placed on islands nor where the approach is not paved.
> e) It should not be located in an area subject to flooding.
> f) It should be possible to park the maintenance truck close to the cabinet.
>
> In addition, we provide a concrete pad in front of the cabinet where the surrounding area is unpaved or landscaped.
>
> Our controller cabinets are provided with numerous other features dedicated to the technician. These include: signal test switches and pushbuttons, work lights, outlets, door holders, limitation of number of wires on a terminal, fade-proof wiring diagrams, interior "flash" switch that permits controller unit to remain in operation in flash position, and mercury-displacement lighting contactors with test switch.
>
> Another controller cabinet feature is the standardization of solid state load switches, flash relays and detector sensor connectors. This simplifies maintenance replacement by permitting interchangeability among manufacturers (*68*).

McDonnell (*73*) has pointed out that "good preventive maintenance" begins with and depends on proper installation." His suggestions included the following:

- Poles should be properly tamped and guyed.
- Provide drainage for conduit runs at handholes or at lowest point of run if other than handhole.
- Positively ground the controller cabinet and neutral side of the service and the pole (if it is metal) by means of a suitable rod. Some sandy locations will require the use of a grounding grid of three or more rods properly spaced and tied in.
- Install cable with sufficient spares, make waterproof splices that are accessible, and make neat and firm connections inside the cabinet.
- Prepare a complete wiring diagram for the entire intersection, locating every cable run, splice, and handhole location.
- Where natural gas is in use and there are underground cable runs entering the cabinet, vent both the top and bottom of the cabinet to promote circulation of air.

The Federal Highway Administration has published *Traffic Control Devices Handbook* (*74*) in which best current practices in traffic signal installation and maintenance are described.

Traffic engineers often complain that their detection loops fail after only six months to a year, forcing either expensive replacement or else operating that phase in a non-traffic-responsive manner. Installation techniques and materials that will prolong loop life are fully described in recent literature. The best single improvement seems to be the encasement of the loop wire in plastic tubing before installation. A blowtorch is used to seal the tubing to the wire at each end. The original paper by Burmeister and Parsonson (*67*) has been supplemented by a report by Bikowitz and Ross of the New York State D.O.T. (*75*) and by a detailed and thorough *Traffic Detector Handbook* prepared for the Federal Highway Administration by Diaz, Seckinger & Associates (*76*). Evidence reported in these publications suggests that encasement allows the wire to withstand the stresses of cracks opening as much as 1 in. (25 mm) in width.

Signal Timing and Phase

Technical control of the maintenance work should rest directly with that part of the organization responsible for signal operations. With regard to signal phasing and timing, certain malfunctions and breakdowns have the potential to cause the maintenance personnel to operate the signals at a downgraded level. At the same time, it is not the function of the signal maintenance unit to make unauthorized changes to phasing, timing, or offsets. The traffic department can keep control over this problem by developing a set of contingency timing and phasing plans covering potential malfunctions and breakdowns. These records become part of the permanent plans for the intersection. Maintenance personnel should be responsible for informing the traffic engineer whenever a contingency plan is used (*2*).

Inspection Frequency and Depth

The inspection problem is one of providing an adequate number of acceptably well-trained inspectors so that traffic signals and signal systems designed at the correct level of sophistication can be used to provide for the safe and efficient movement of traffic (T. Hicks, personal communication, 1984).

Inspection frequency and depth ought to be based on the history of required service at the location, and on the criticality of the intersection. In practice, however, the prime determinant of inspection frequency and depth seems to be the availability of pesonnel (*2*).

Appendix A includes a checklist and field completion form for regularly scheduled inspections.

The following material on inspection was prepared for this report by Thomas Hicks of the Maryland DOT (T. Hicks, personal communication, 1984). The organization of most state highway agencies, and perhaps that of many counties and larger cities, requires the inspection to deal with many kinds of projects. Most of these involve the construction of highways and bridges; the amount of work in the traffic signal and electrical area is relatively small.

This situation has become a problem, particularly with the great advances that have occurred in electronic technology, because the inspection force has very limited experience and, therefore, practically no capability or competency in dealing with sophisticated traffic signal work. There are several ways to overcome this, such as through the use of a smaller group of inspectors trained and assigned to handle this type of work, or the use of staff from the traffic engineering unit who serve as inspectors on traffic-signal projects. The Maryland DOT has chosen a combination of the two, with emphasis on the latter. They have traffic-signal inspectors in the Office of Traffic who serve statewide but handle only the electrical and electronic parts of the project. The regular district inspection staff handles the construction-related work. At the same time, Maryland does provide training in the electrical/electronic area for certain of the regular inspection staff.

A second way that Maryland has attempted to overcome the problem of adequate inspection is through division of the inspection work load between the regular inspection staff and the inspectors in the Office of Traffic. The inspection for the major and more formally advertised projects follows the normal State Highway Administration inspection procedures and policies. In this work the Office of Traffic inspectors assists as just explained. The inspection for the relatively minor and informally processed traffic-signal work is handled entirely by the Traffic inspectors. In these latter instances the field districts have no responsibility and the entire construction procedure is handled by the Office of Traffic.

Another method of overcoming the problem of an insufficient number of trained inspectors for traffic-signal work is through the use of contract inspection services. Maryland is not as yet doing this but is preparing to undertake a one-year contract with an engineering firm to provide manpower for traffic-signal inspection purposes. The State Highway Administration currently uses contract inspectors on other types of construction.

Traffic-signal inspection includes the preparation of a "punch list," which is a listing of the things that the inspector finds that need to be corrected or redone by the contractor in order for the signal installation to pass inspection. The traffic inspector must be thoroughly familiar with the many fine details of traffic-signal components, installation, and operation. The punch list is one part of the essential communication process between the contractor and the governmental agency's units of design, construction, inspection, and operation.

Inspector training is especially critical in the traffic-signal area because of the rapid technological changes that have taken place and because of the unfamiliarity of most construction inspectors with traffic-signal equipment. In Maryland, training sessions on traffic-signal inspection are held annually, usually during the winter months when construction activities are at a low point.

Problems of design and operation often will not become apparent until a traffic signal or signal system is constructed. At that time the inspectors realize that what has been specified is not appropriate or perhaps, not even possible. There needs to be feedback to the designer at this point so that needed improvements can be made in the preparation of plans, special provisions, and specifications. However, this feedback is often slow or missing entirely. The communications chain fails to form a closed loop. It is essential that some regular process of cooperative review be established involving the construction inspectors and the original designers.

Finally, the chief Engineer should develop and issue a good procedure establishing the rules of communication as well as the requirements for preliminary reviews, final reviews, preconstruction meetings, ongoing construction meetings, and final inspection meetings. A good communications procedure nearly eliminates problems of miscommunications or misunderstandings (T. Hicks, personal communication, 1984).

"As-Built" Plans and Documentation of Later Changes

Construction drawings ought to depict accurately the intersection as actually built and should be kept updated as changes are made. The location of underground components is especially important. Most agencies retain the original construction drawings, but relatively few try to update them to reflect all field changes.

Changes are likely to occur during construction, particularly if the design was not prepared using detailed surveys of the location. Changes may also occur after construction if (a) the power company relocates the service; (b) work is performed by private contractors, public utilities, etc.; and (c) maintenance is performed, such as relocation of conduit runs, use of spare conductors, relocation of splice boxes, etc.

When major signal reconstruction or modernization is planned, the redesigns need to be based on "as-built" plans that have been kept current. If these are not available the redesigns may be difficult to carry out or may not make full use of existing facilities (*2*).

Service Histories

Virtually every organization performing traffic-signal maintenance keeps records of work performed at the various locations. Policies and practices vary widely from agency to agency. Many attorneys representing plaintiffs in automobile accident cases are aware of record-keeping standards and guidelines, such as those published by the IMSA (*25*). It is important that office records be supplemented by a card in each curbside cabinet, so that a technician making a trouble call can be aware of the service history over the past few hours, days, and weeks.

Summary of Policies and Practices

The variety of approaches to service-history record keeping can be summarized into a few general types. Many agencies keep good records of each intersection, either as a collection of filled-out forms in a file folder or as a ledger in which a new line of information is added for each trouble call to that location. (Sample forms and ledgers are found in the appendixes.) "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" (*2*).

In the past, some jurisdictions did no more than file the reports on a chronological basis. This makes access to the records of a specific location almost impossible, except that it is easy to locate the records in connection with an accident that took place on a certain date.

Policies on access to documentation by individuals outside the agency seem to vary widely.

An increasing number of agencies have computerized their service-history records. All dispatching records, work orders, work-order-completion reports, trouble-call reports, and inspection check lists are entered into computer storage, to be recalled in a convenient format when required (*2*).

Examples of Computerized Service Histories

Two examples of computerized maintenance-history files are presented next. One is from the New York State D.O.T. and the other from the city of Cincinnati, Ohio.

The New York State D.O.T. prepares a quarterly Traffic Signal Inventory System and Maintenance History on its more than 2500 stop-and-go signals, flashers, and beacons (D. Russo, personal communication, 1982). Figure 28 is a sample page from the signal-by-signal accounting of the work performed. Figure 29 summarizes all of these pages, showing the number of signals by frequency of calls for various types of controllers.

Cincinnati has used a computerized traffic control equipment maintenance summary since the early 1970s (*29*). After five

```
                                      NEW YORK STATE DEPARTMENT OF TRANSPORTATION                        PAGE        1
PROGRAM B/TRAFSIN/N691170           TRAFFIC SIGNAL INVENTORY SYSTEM - MAINTENANCE HISTORY          DATE OF REPORT  3/10/82

                                      FROM:  JANUARY     1981   TO:  DECEMBER   1981                INV LOC: 66    R/C: 61

                PERS CALL ARR* SIGL LEFT  *****REASON*****  *****ACTIVITY******  ********************EQUIPMENT********************
 DATE     HOURS CODE RECO SIGL OPER SIGL                                          REPAIR        REMOVE        REPLACE       ADJUST

******** SIGNAL NUMBER:           INSP-CONTR  ROUTE: XXXX  CLASS: NSCS  DETECTOR: SIGNAL HAS NO DETECTOR RECORDS

         SIGNAL NUMBER:           INSP-CONTR HAD     0 EMERGENCY REPAIR CALLS REPORTED


******** SIGNAL NUMBER:          6            ROUTE:  19   CLASS: SSNS  DETECTOR: PRESSURE SENSITIVE - DIRECTIONAL

 2/04/81    1 R  01  0000 1040       1109  SCHEDULED REPAIR                          PED PUSH BUT

 2/27/81    2 R  01  0000 1030       1110  INSPECT/RELAMP                                                        BULBS
                                                                                                                 CONTROLLER
12/24/81    6 R  02  0930 0930       1130  SCHEDULED REPAIR                                                      OTHER AUX

         SIGNAL NUMBER:          6            HAD    0 EMERGENCY REPAIR CALLS REPORTED


******** SIGNAL NUMBER:         11            ROUTE: 305   CLASS: SANS  DETECTOR: SONIC MOTION

 1/13/81    1 R  01  0000 1100       1135  SCHEDULED REPAIR                                                      BULBS         DETECTORS

 1/30/81    1 R  04  0000 1015       1045  SCHEDULED REPAIR                                                      BULBS
                                           BULB FAILURE

 2/26/81    2 R  01  0000 0930       1025  INSPECT/RELAMP                                                        BULBS

11/10/81    1 R  01   1235 1235      1300  SCHEDULED REPAIR                                                      OTHER AUX

12/19/81    4 O  04  0415 0530 0615 0630  ACCIDENT        PLACED ON RECALL     EXT WIRE

12/23/81   24 R  02  0000                  SCHEDULED REPAIR                      OTHER AUX
                                                                                 EXT WIRE
                                                                                 CABNT STRUCT

         SIGNAL NUMBER:         11            HAD    2 EMERGENCY REPAIR CALLS REPORTED


******** SIGNAL NUMBER:         12            ROUTE: 417   CLASS: SSNS  DETECTOR: LOOP DETECTOR - SOLID STATE

 2/25/81    2 R  04  0000 0945       1045  INSPECT/RELAMP                                                        BULBS

 2/25/81    2 R  04  0001 1100       1200  INSPECT/RELAMP                                                        BULBS

 3/04/81    1 R  01  0000 1030       1100  SCHEDULED REPAIR                                                      SIGNS

 4/06/81    2 O  04  2200 2330 2400 2405  SIGNAL STUCK                                                           DETECTORS

Note:  The classification code is S for state maintained, A for actuated, N for normal three color operation including
       any arrows, and F for fully traffic responsive.
```

FIGURE 28 Example page from New York State D.O.T. quarterly maintenance history.

NEW YORK STATE DEPARTMENT OF TRANSPORTATION
PROGRAM B/TRAFSIN/N691180 TRAFFIC SIGNAL INVENTORY SYSTEM - MAINTENANCE SUMMARY DATE OF REPORT 3/10/82

NUMBER OF SIGNALS BY FREQUENCY OF CALLS FROM: JANUARY 1 1981 TO: DECEMBER 31 1981 INV LOC: 66 SIGNAL-TYPE: STATE

	·········FULL ACTUATED·········							·········SEMI ACTUATED·········							······PRETIMED & FLASHER······							TOTAL
REASON	1	2	3	4	5	>5	AVG.	1	2	3	4	5	>5	AVG.	1	2	3	4	5	>5	AVG.	CALLS
INSPECT CONTRACT	0	0	0	0	0	0	0.0	0	0	0	0	0	0	0.0	0	0	0	0	0	0	0.0	0
PREVENTIVE MAINT	10	0	0	0	0	0	1.0	3	0	0	0	0	0	1.0	2	0	0	0	0	0	1.0	15
RELAMPING	5	0	0	0	0	0	1.0	2	0	0	0	0	0	1.0	0	0	0	0	0	0	0.0	7
MODIFICATION	5	0	0	0	0	0	1.0	0	0	0	0	0	0	0.0	0	0	0	0	0	0	0.0	5
SCHEDULED REPAIR	4	4	5	11	1	6	3.8	3	8	2	1	1	2	2.7	4	2	2	0	0	0	1.7	180
UNKNOWN	0	0	0	0	0	0	0.0	0	0	0	0	0	0	0.0	0	0	0	0	0	0	0.0	0
ACCIDENT	5	0	0	2	0	0	1.8	1	0	0	0	0	0	1.0	1	0	0	0	0	0	1.0	15
LIGHTNING	3	0	0	0	0	0	1.0	0	0	0	0	0	0	0.0	0	0	0	0	0	0	0.0	3
POWER FAILURE	1	0	0	0	0	0	1.0	1	0	0	0	0	0	1.0	0	0	0	0	0	0	0.0	2
SIGNAL STUCK	8	0	1	0	0	0	1.2	5	1	1	0	0	0	1.4	1	0	0	0	0	0	1.0	22
SKIP PHASE	1	0	0	0	0	0	1.0	0	0	0	0	0	0	0.0	0	0	0	0	0	0	0.0	1
STORM DAMAGE	1	0	0	0	0	0	1.0	3	0	0	0	0	0	1.0	0	0	0	0	0	0	0.0	4
TIMING PROBLEM	10	3	0	0	0	0	1.2	4	0	0	0	0	0	1.0	0	0	0	0	0	0	0.0	20
TUNING PROBLEM	3	1	0	0	0	0	1.2	0	0	0	0	0	0	0.0	0	0	0	0	0	0	0.0	5
VANDALISM	2	0	0	0	0	0	1.0	2	0	0	0	0	0	1.0	1	0	0	0	0	0	1.0	5
ON FLASH-MONITOR	3	3	1	1	0	0	2.0	1	0	0	0	0	0	1.0	0	0	0	0	0	0	0.0	17
ON FLASH-OTHER	1	1	0	0	0	0	1.5	2	0	0	0	0	0	1.0	0	0	0	0	0	0	0.0	5
FALSE CALL	0	1	0	0	0	0	2.0	0	0	0	0	0	0	0.0	0	0	0	0	0	0	0.0	2
BULB FAILURE	5	3	0	0	0	0	1.3	5	2	0	0	0	0	1.2	0	0	0	0	0	0	0.0	20
IMPROPER INDICAT	2	1	1	0	0	0	1.7	1	0	0	1	0	0	2.5	4	0	0	0	0	0	1.0	16
INSPECT/RELAMP	30	0	0	0	0	0	1.0	19	1	0	0	0	0	1.0	25	0	0	0	0	0	1.0	76
																					TOTAL	420

FIGURE 29 Example page from New York State D.O.T. quarterly maintenance summary.

years of use of these summaries Cincinnati was able to reduce the number of chronically malfunctioning intersection controls from 17 in 1973 to only 2 in 1977. The city has more than 700 traffic signals. See Appendix I for more details of their computerized reporting.

A description of Cincinnati's maintenance summary begins with the radio dispatcher's log (B. McKay, personal communication, 1984). When receiving a call and dispatching a crew the dispatcher fills out a form with the following entries:

Who phoned in complaint or radioed it in
Date, time, intersection code number
Location and direction or corner
Description of complaint or trouble
Code number of maintenance technician
Time of day when referred to maintenance
Initials of repairer
Time of day when repair completed
Code numbers for complaint reported and that actually found

Some of these items cannot be completed until the crew calls back with its findings and repair activity. Once a week the dispatcher sends all completed logs to the engineering office, where a clerk codes the remaining items for computer input and sends the completed logs to the Electronic Data Processing (EDP) Division.

On a quarterly basis EDP sends back several reports. These reports contain the malfunctions from the previous four calendar quarters. The report that contains one complete calendar year is filled permanently for historical and legal purposes.

[Figure 30] is the standard report. Larger cities will generate a bulky report and it is helpful to develop a chronic problem list to help pinpoint trouble spots. This is [Figure 31]. This report is generated by listing all intersections which have had more than twenty complaints in the last four calendar quarters and three or more complaints in the last reported month. This report is distributed to the maintenance section with instructions to place special maintenance attention on these locations. On occasion they find that the problem is caused by inadequate design and it is referred to the design section for attention.

Using a computerized intersection equipment inventory, and cross referencing it with the data which compiled [Figure 31], we can readily compile a component failure list as shown in [Figure 32] (B. McKay, personal communication, 1984).

At the end of each component list in Figure 32 there is a "Failure Ratio," the formula for which is as follows:

$$\text{Failure Ratio} = \frac{\text{No. of failures of a specific model}}{\text{Total no. of failures for all controllers}} \times \frac{\text{Total no. of controllers or detectors}}{\text{Total no. of a specific model}}$$

where for a typical report period the following data might apply:

Total no. of controllers	639
Total no. of controller failures	1301
Total no. of detectors	290
Total no. of detector failures	130

TRAFFIC SIGNAL MALFUNCTION REPORT

REPORT DATE 03/21/84

INTERSECTION LISTING

LOCATION	DATE			REPORTED		ACTION TAKEN			BY
MADISON & HILLSBRAE & WOODLAND	04/13/83	1015A	N.	VEH SIGNAL TIMING	VEH SIGNAL			OTHER	C R
MADISON & HILLSBRAE & WOODLAND	12/24/83	1200P	ALL	VEH SIGNAL OUT OF ORDER	VEH SIGNAL			NO ACTION	
MADISON & RED BANK EXPY	01/31/83	0200A	ALL	VEH SIGNAL STUCK	0			PER COS	R H
MADISON & RED BANK EXPY	05/03/83	0705A	ALL	VEH SIGNAL FLASHING	CONTROLLER		SWITCHED TO		C R
MADISON & RED BANK EXPY	06/15/83	2405A		ISLAND LIGHTDOWN	ISLAND LIGHT		REPLACED		
MADISON & RED BANK EXPY	07/09/83	1510P	ALL	VEH SIGNAL STUCK	CONTROLLER		SWITCHED TO	NORMAL CYCLE	184
MADISON & RED BANK EXPY	07/21/83	2050P	ALL	VEH SIGNAL STUCK			NO ACTION		1 M
MADISON & RED BANK EXPY	07/21/83	2323P	ALL	VEH SIGNAL OUT OF ORDER	VEH SIGNAL		FLASHING	SWITCHED TO	D A
MADISON & RED BANK EXPY	07/27/83	2130P	E.	VEH SIGNAL OUT OF ORDEP	VEH SIGNAL	LAMP	RED	REPLACED	LTW
MADISON & RED BANK EXPY	07/27/83	2130P	W.	VEH SIGNAL OUT OF FOCUS	VEH SIGNAL			REFOCUSED	LTW
MADISON & RIDGE	05/08/83	0949A	ALL	VEH SIGNAL OUT OF ORDER	CONTROLLER	WIRING 110 V		REPAIRED	C R
MADISON & RIDGE	11/02/83	0750A	N.	VEH SIGNAL OUT	VEH SIGNAL	LAMP	RED	REPLACED	W R
MADISON & STEWART	02/14/83	1330P	ALL	VEH SIGNAL FLASHING	CONTROLLER		REPLACED		W B
MADISON & STEWART	04/02/83	1845P	ALL	VEH SIGNAL OUT	CONTROLLER		SWITCHED TO	NORMAL CYCLE	U.O
MADISON & STEWART	07/02/83	0445A		PUSH BUTTON DAMAGED	PUSH BUTTON	0	ARROW	REPAIRED	J M
MADISON & STEWART	09/11/83	1715P		PED SIGNAL OUT OF ORDER	PED SIGNAL	TRANSFORMER		REPLACED	J B
MADISON & STEWART	12/24/83	2114P	ALL	VEH SIGNAL OUT OF ORDER	VEH SIGNAL		FLASHING	SWITCHED TO	C A
MADISON & VICTORY PKWY	02/15/83	1430P		CABLE OTHER	CABLE			PER COS	LTW
MADISON & VICTORY PKWY	02/16/83	0745A		CABLE OTHER	CABLE			OTHER	U N
MADISON & VICTORY PKWY	02/24/83	0950A		CABLE OTHER	CABLE			REPAIRED	W R
MADISON & VICTORY PKWY	04/18/83	0831A	E.	VEH SIGNAL OUT	VEH SIGNAL	LAMP	RED	REPLACED	W R
MADISON & VICTORY PKWY	06/07/83	0759A	IN	VEH SIGNAL OUT	VEH SIGNAL	LAMP	GREEN	REPLACED	W R
MADISON & VICTORY PKWY	07/08/83	0045A		POLE OUT OF ORDER	CABLE			OTHER	184
MADISON & VICTORY PKWY	08/15/83	0800A	W.	VEH SIGNAL OUT OF ORDER	VEH SIGNAL	LAMP	RED	REPLACED	M M
MADISON & VISTA	03/14/83	1630P	IN	VEH SIGNAL OUT OF ORDER	VEH SIGNAL	LAMP	GREEN	REPLACED	LTW
MADISON & VISTA	05/31/83	0510A	ALL	VEH SIGNAL STUCK	DETECTOR	0	ARROW	ADJUSTED	D H
MADISON & VISTA	06/09/83	1830P	ALL	VEH SIGNAL FLASHING	FLASHER			REPLACED	U.U
MADISON & VISTA	06/22/83	1930P	ALL	VEH SIGNAL STUCK	CONTROLLER	TRANSFORMER		REPLACED	181
MADISON & VISTA	07/22/83	1900P	ALL	VEH SIGNAL STUCK	CONTROLLER	RATCHET ASS.		ADJUSTED	181
MADISON & VISTA	07/26/83	1830P	ALL	VEH SIGNAL FLASHING	CONTROLLER		REPLACED	DIAL TRANS.	181
MADISON & VISTA	08/01/83	2230P	E.	VEH SIGNAL OUT OF ORDER	VEH SIGNAL				J B
MADISON & VISTA	08/01/83	2230P	E.	VEH SIGNAL OUT OF ORDER	VEH SIGNAL			PER COS	J B
MADISON & VISTA	08/12/83	0600A	ALL	VEH SIGNAL OUT OF ORDER	CONTROLLER		RELAY	TIGHTENED	URF
MADISON & VISTA	12/16/83	0757A	ALL	VEH SIGNAL STUCK	CONTROLLER		RELAY	REPLACED	R L
MADISON & WHETSEL	02/07/83	1020A	S.	PED SIGNAL OTHER	PED SIGNAL	LAMP		REPLACED	D H
MADISON & WHETSEL	09/15/83	2200P	IN	VEH SIGNAL OUT OF ORDER	VEH SIGNAL	LAMP		REPLACED	LTW

FIGURE 30 Example of Cincinnati's standard report of traffic-signal malfunctions.

T R A F F I C   S I G N A L   M A L F U N C T I O N   R E P O R T

REPORT DATE 04/04/83

C H R O N I C   P R O B L E M S

LOCATION	DATE			REPORTED			ACTION TAKEN		BY
HARRISON & MCHENRY	01/01/82	1055A		VEH SIGNAL	STUCK	FLASHER	WIRING	REMOVED	TLU
HARRISON & MCHENRY	01/01/82	1055A		VEH SIGNAL	STUCK		WIRING	REMOVED	TGU
HARRISCN & MCHENRY	01/06/82	1307P		VEH SIGNAL	OUT OF ORDER			NO ACTION	
HARRISCN & MCHENRY	01/06/82	1307P		VEH SIGNAL	OUT OF ORDER			INOPERATIVE	
HARRISCN & MCHENRY	01/19/82	0712I	ALL	VEH SIGNAL	FLASHING	CONTROLLER	SWITCHED TO	NORMAL CYCLEC	R
HARRISON & MCHENRY	01/19/82	0712A	ALL	VEH SIGNAL	FLASHING	CONTROLLER	SWITCHED TO	NORMAL CYCLEC	A
HARRISON & MCHENRY	01/21/82	1717P		PED SIGNAL	OUT OF ORDER	PED SIGNAL	LAMP DONT WALK	REPLACED	C A
HARRISON & MCHENRY	02/04/82	1615P		VEH SIGNAL	OTHER			OTHER	D M
HARRISON & MCHENRY	03/22/82	1430P		VEH SIGNAL	OUT OF ORDER	VEH SIGNAL	DOOR	CLOSED	C A
HARRISON & MCHENRY	03/30/82	1614P	W.	VEH SIGNAL	OUT OF ORDER	VEH SIGNAL	LAMP GREEN	NO ACTION	
HARRISON & MCHENRY	03/31/82	0756A	N.	VEH SIGNAL	OUT OF ORDER	VEH SIGNAL	LAMP GREEN	REPLACED	J R
HARRISCN & MCHENRY	03/31/82	1015A	ALL	VEH SIGNAL	STUCK	CONTROLLER	TIMER	REPLACED	C R
HARRISON & MCHENRY	08/03/82	0700A	ALL	VEH SIGNAL	FLASHING	CONTROLLER	RETIMED		C R
HARRISON & MCHENRY	09/01/82	1218P	W.	VEH SIGNAL	OUT OF ORDER	VEH SIGNAL	LAMP RED	REPLACED	J R
HARRISCN & MCHENRY	09/14/82	0310A	ALL	VEH SIGNAL	STUCK			NO ACTION	
HARRISON & MCHENRY	09/14/82	0310A	ALL	VEH SIGNAL	STUCK			INOPERATIVE	
HARRISCN & MCHENRY	09/14/82	0752A	ALL	VEH SIGNAL	FLASHING	VEH SIGNAL		PER CDS	C R
HARRISON & MCHENRY	11/21/82	1717P		PED SIGNAL	OUT OF ORDER	PED SIGNAL	LAMP DONT WALK	REPLACED	C A
HARRISON & MCHENRY	12/12/82	1700P		VEH SIGNAL	OUT OF ORDER	VEH SIGNAL	FUSE	SWITCHED TO	R 6
HARRISON & MCHENRY	12/13/82	0651A	ALL	VEH SIGNAL	FLASHING	CONTROLLER	OTHER		C R
HARRISON & MCHENRY	12/29/82	1507P		PED SIGNAL	OUT OF ORDER	PED SIGNAL	LAMP	REPLACED	J R

FIGURE 31 Example of Cincinnati's report of locations with chronic problems.

TRAFFIC SIGNAL MALFUNCTION REPORT

REPORT DATE 03/21/84

COMPONENT LISTING

COMPONENT	MAKER	MODEL	CODE			ACTION TAKEN	LOCATION	DATE
VEH SIGNAL				WIRING		REPAIRED	GRAND & WESTWOOD	04/05/83
VEH SIGNAL				WIRING		REPAIRED	KEMPER & MCMILLAN	01/21/83
VEH SIGNAL				SCHOOL	CLOCK	RESET	QUEEN CITY & ST FRANCIS HOSP	01/07/83
VEH SIGNAL				DOOR			GRACELY & RIVER RD	11/29/83
VEH SIGNAL				DOOR	RED		ERKENBRECHER & VINE	01/03/83
VEH SIGNAL			6			REPLACED	CENTRAL & NINTH	07/00/83
VEH SIGNAL			6		RED	REPLACED	MCMILLAN & VINE	06/16/83
VEH SIGNAL				SWITCH		RESET	HARTWELL & SHADYCROOK & VINE	07/16/83
CONTROLLER	ALL MFR	ALL	802			REPLACED	ELBERON,STATE & WARSAW	09/02/83
CONTROLLER	ALL	FLASHER	802		GREEN	RESET	GLENWAY & CARSON SCH	12/05/83
CONTROLLER	ALL	FLASHER	802	CIRCUIT BR.		RESET	LINN & POPLAR	12/16/83
CONTROLLER	ALL	FLASHER	802		RELAY	REPLACED	LINN & WASHBURN SCH	01/19/83
CONTROLLER	ALL	FLASHER	802	TIMER	DUAL	REPLACED	LINN & WASHBURN SCH	01/19/83

FAILURE RATIO = 0.08
TOTAL MODELS = 95
TOTAL FAILURES = 5

COMPONENT	MAKER	MODEL	CODE			ACTION TAKEN	LOCATION	DATE
CONTROLLER	KENTRON	PRETIME	061			REPLACED	GLENWAY & QUEBEC,SETON,WARSAW	03/02/83
CONTROLLER	KENTRON	PRETIME	061		NORMAL CYCLE		GLENWAY & QUEBEC,SETON,WARSAW	01/26/83
CONTROLLER	KENTRON	PRETIME	061	DIAL UNIT MOTOR		REPLACED	GLENWAY & QUEBEC,SETON,WARSAW	01/13/83
CONTROLLER	KENTRON	PRETIME	061	DIAL UNIT MOTOR		REPAIRED	GLENWAY & QUEBEC,SETON,WARSAW	12/24/83

FAILURE RATIO = 2.01
TOTAL MODELS = 3
TOTAL FAILURES = 4

COMPONENT	MAKER	MODEL	CODE			ACTION TAKEN	LOCATION	DATE
CONTROLLER	GEN ELEC	TYPE F	081			REPLACED	LINCOLN & READING,UNIVERSITY	06/09/83
CONTROLLER	GEN ELEC	TYPE F	081			REPLACED	LINCOLN & READING,UNIVERSITY	11/25/83
CONTROLLER	GEN ELEC	TYPE F	081		NORMAL CYCLE		ERIE & PAXTON	05/05/83
CONTROLLER	GEN ELEC	TYPE F	081	RATCHET ASS.		CLEANED	TAFT & WOODBURN	02/07/83
CONTROLLER	GEN ELEC	TYPE F	081	CAM SHAFT			CHASE & KIRBY	12/24/83
CONTROLLER	GEN ELEC	GEF	081	CAM SHAFT		CLEANED	MAY & TAFT	12/30/83
CONTROLLER	GEN ELEC	TYPE F	081	MASTER		OTHER	BURNET & UNIVERSITY	09/20/83

FAILURE RATIO = 0.46
TOTAL MODELS = 23
TOTAL FAILURES = 7

COMPONENT	MAKER	MODEL	CODE			ACTION TAKEN	LOCATION	DATE
CONTROLLER	KENTRON	PRETIME	061	CONTACTS		ADJUSTED	JEFFERSON & UNIVERSITY	01/26/83

FIGURE 32 Example of Cincinnati's report of component failures.

The formula is such that a failure ratio of 1.0 indicates average performance and a ratio of 2.0 indicates twice as many malfunctions as an average component.

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 Summary

Inventory control in larger organizations is computerized and includes reorder procedures (Figure 33).

Both of the common methods of inventory control make additions to inventory as items are received, but they differ in their handling of subtractions. In one method subtractions from inventory are made on the basis of "withdrawal records," whereas the other method is based on "use records." 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 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 (*2*).

Baltimore's Microcomputer-Based Inventory System

The City of Baltimore's Department of Transit and Traffic has installed a microcomputer-based traffic signal inventory system (*77*). It is designed to manage the record-keeping functions of Baltimore's electronics division, which is responsible for the city's 1,100 signalized intersections. At present, Baltimore has approximately 22 different types of devices, totaling over 5,000 pieces of equipment that are in use, in repair, or in stock.

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 4B 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					
29G	0101 060	DISPENSER FOR FOLDED PAPER TOWEL	06-24-	*	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	016465	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	05-13-72	*	2295	0	2293	3315	1123.7					
32C	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/701T	09-07-72		28	0	26	50	20.2					
33D	0271 462	HOLDER FUSE BUSS # HFB	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	345	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	435.7	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 33 Computer inventory printout (*2*).

Inventory Package

The inventory package includes the following files:

Location Record (in use, in repair, or in stock)
Device Record
History Location Record
History Device Record
Electronic Parts Inventory
Personnel File
Vendors File
Radios
Vandalism File
Trouble-Incident Summary
Electronic Specification Reference Manual
Shipping/Receiving Records of Electronic Parts and Devices

Information Entry

The system provides entry routines for the following information: (a) additions (the input of basic information about a new item), (b) receipts (input of purchase order numbers, date of receipt, number received, and price per item), (c) withdrawals (input of the "use code" to indicate what the item was used for, date of withdrawal, and number withdrawn), and (d) physical count adjustments (input of adjustments to physical counts).

Reports

The Baltimore system provides the following reports on command:

- Inventory—A printout of all items in inventory showing all information about each item. The program has the option of producing this report on a sorted or selected basis as follows: Item Number (sorted by item number or for selected item numbers only), Location Code (sorted by location number or for selected location numbers only), or Vendor Report (sorted by vendor or for selected vendors only).
- Receipts Journal—The system prints a journal showing all receipts during a given period.
- Withdrawal Journal—Journal of all withdrawals.
- Adjustment Journal—All items that were adjusting during the given period.
- Reorder Report—A report printed at any time that shows all items that are at or below their reorder level.

Inquiries

The system is capable of providing complete and current information on the screen about any item in the inventory with a minimum number of commands.

Data Base Manager

The software manages the data base to allow the entry of information in the form of records. Each record is allowed at least 100 fields of up to 256 characters each. Multiple-level sorts are performed in a single pass and require less than 8 minutes per 1000 records.

Word Processing

The Baltimore system also includes a function-key oriented word processor with a file-merging option and spelling dictionary.

Special Reports

The system is designed to respond to special requests for data, as shown in the following examples:

Suppose that a communications control terminal (the CCT or controller) arrives in the shop for repair. The previous day there was communication-line trouble that affected a series of intersections. It is important to know whether this particular CCT was affected by that com-line problem. The solution is to call up that intersection and check to see if it was included with the list of intersections affected by that problem. If so, it will save the technician several hours of unnecessary tests to effect the repair. By keeping a record of the location of these devices, technicians are able to determine more readily if the problem is with the device or at the intersection.

Suppose that a communications center trouble ticket comes in indicating unauthorized entry to the cabinet and both the controller and green conflict monitor are missing. What were the serial numbers of the missing devices? The solution is to call up the intersection and check the serial numbers of the devices that were last reported to be at that intersection. These records will pinpoint serial numbers on equipment stolen. Not only does this keep intersection records accurate, but it also supports other files maintained for the department, such as inventory, budget requests, and so on.

Problem Intersections

Intersections that have an excessive number of change-outs of equipment over a designated period of time are flagged to the operator's attention.

Baltimore's Examples

Figures 34 through 37 show examples of the inventories and reports. The history of a device is shown tracked in Figure 37, and includes where and when the device has been deployed up to and including the current location. On the average, a device may complete the change-out cycle a minimum of 10 times during its life of 5 to 20 years. For 2000 devices, for example, this file could become extremely large.

The Device History has a subcategory named Device Repair History that pertains only to the controller units and their six printed circuit boards. This history may become massive if each board had to be repaired once a year; 1,200 controllers times 6 boards times 20 years equals 144,000 entries.

TRAFFIC CONTROL EQUIPMENT DEVICE RECORD / INVENTORY

	DEVICE SERIAL NUMBER	DEVICE NAME	DEVICE MODEL NUMBER	MFG. CODE.	LOCATION CODE	LOCATION	DATE INSTALLED	DATE REMOVED
[A]	2345	CCT	2 Ø	123	1234	Lombard & Greene	01/22/82	
[B]	3345	CCT	3 Ø	123	1100	MX4 Electronics	01/23/82	
[C]	2346	GCM	2 Ø	233	1111	Shop - Repair	01/24/82	
[D]	3347	GCM	3 Ø	233	1110	Shop - Stock	01/24/82	
	1234	RADAR	RDIA	300				
	123456	DETECTOR	Proximeter	301				
	123456	DETECTOR	USDP	302				
	1234567	DETECTOR	SOP	303				
[E]	123456	DETECTOR	SPDR-1	304	DATA TO BE ENTERED SAME AS A - D ABOVE			
	123456	DETECTOR	TSVDM	305				
	1234	DETECTOR	SVDM	306				
	123	DETECTOR	M-110	307				
	123	DETECTOR	M-210	308				
	12-345	CONTROLLER	110 RC	400				
	12-345	CONTROLLER	110-2 RC	401				
	123456	CONTROLLER	MM-2	402				
	123456	CONTROLLER	MM-3	403				
[F]	123456	CONTROLLER	505	404	DATA TO BE ENTERED SAME AS A - D ABOVE			
	123456	CONTROLLER	804	405				
	123456	CONTROLLER	877	406				
	123456	CONTROLLER	1022	407				
	123456	CONTROLLER	1033	408				
	1234567890	CONTROLLER	1826	409				
	1234567890	CONTROLLER	HMP-20	410				

FIGURE 34 Baltimore's device record/inventory.

ADMINISTRATIVE CONTROL

This section focuses on the determination of failure rates and repair times in order to stock spares appropriately and to assign priorities for equipment replacement programs. The reader will find more data on failure rates, maintenance work units, and costs in Chapter 6.

Determination of MTBF

The mean time between failures (MTBF) is calculated from the following equation:

$$\text{MTBF} = \frac{\text{Number of Units} \times \text{Observation Period}}{\text{Number of Failures}}$$

TRAFFIC CONTROL EQUIPMENT DEVICE RECORD INVENTORY REPORT

DEVICE SERIAL NUMBER	DEVICE NAME	DEVICE MODEL NUMBER	MFG. CODE	LOC. CODE	LOCATION	DATE INSTALLED
2345	CCT	2 Ø	123	1234	Lombard & Greene	01/22/82
2346	CCT	2 Ø	123	0598	Baltimore & Light	04/08/80
2347	CCT	2 Ø	123	0299	Hanover & Heath	05/10/81
2997	GCM	2 Ø	233	1234	Lombard & Greene	03/03/82
2998	GCM	2 Ø	233	1028	Franklin & Franklintown	03/10/79
2999	GCM	2 Ø	233	1510	Pratt & Light	04/23/81
3000	GCM	3 Ø	233	1508	Eastern & Ponca	05/09/80

FIGURE 35 Baltimore's device-inventory report.

TRAFFIC CONTROL EQUIPMENT INTERSECTION INVENTORY REPORT

LOC. CODE	LOCATION	DEVICE NAME	DEVICE S/N	DATE INSTALLED	DEVICE NAME	DEVICE S/N	DATE INSTALLED
1234	Pratt & Light	CCT	3345	01/02/81	GCM	3789	03/05/82
1235	Fleet & Broadway	CCT	2102	09/11/82	GCM	2065	11/11/81
1236	Aliceanna & Ann	CCT	2111	05/09/82	GCM	2118	12/25/78

FIGURE 36 Baltimore's intersection-inventory report.

For example, 52 old PR controllers were observed in Atlanta for 6 months (4,380 hours) and 285 failures occurred.

$$\text{MTBF} = \frac{52 \times 4{,}380}{285} = 800 \text{ hr} = 33 \text{ days}$$

This means that *each* of the 52 controllers could be expected to fail once every 33 days, or about 11 times a year. The failure might occur in the controller itself or in an auxiliary unit such as a minor movement controller or advance green timers, or in a load switch. Few of the controllers were solid-state, so not many conflict monitors were involved. Failures of detectors or signal heads were not included.

A system MTBF is calculated as 800/52 = 15 hr, meaning that the system as a whole could expect a failure of one controller or another every 15 hours.

Figure 38 shows the two types of MTBF determinations for the Urban Traffic Control System (UTCS) project carried out in Washington, D.C. (*65*). The system MTBF is labeled UTCS MTBF in the top box of the figure. The lower boxes show the failure tabulations from which the MTBF values were derived. For the vehicle detectors, for example,

$$\text{Subsystem (unit) MTBF} = \frac{497 \times 23{,}328}{111} = 104{,}600 \text{ hr}$$

$$\text{System (UTCS-wide) MTBF} = \frac{104{,}600}{497} = 210 \text{ hr}$$

The concept of mean time between failures (MTBF) as a measure of reliability is in widespread use. Cimento (*39*) noted that it is a valid measure when a large sample of units is considered and when failures are random in occurrence rather than attributable to a design defect.

Cimento researched the failure history of elements of the UTCS in Washington, D.C. and derived a generalized historical profile of failures for typical traffic control system hardware (Figure 39).

> Typically, the failure rate during factory acceptance testing decreases as deficiencies are corrected and units delivered. As installation begins, the quantity of units in operation increases at the same time that field environment conditions are encountered, resulting in the gradual increase in failures. As the "infant mortality" failures decrease again, finally stabilizing at a level indicative of the random failure performance of the particular equipment as designed. . . the peak failure period is often likely to occur during the system acceptance test and evaluation period. Also, a bona fide MTBF calculation cannot be made until a year or more following the normal test and evaluation period (*39*).

Early in Chapter 2 the reader will find supporting evidence from Scheck (*26*) that all types of components fail after random lengths of time, rather than wearing out with age.

Use of MTBF or MTTR to Stock Spares

The stocking of a sufficient supply of spares can be managed best when there is a knowledge of the mean time between failures

TRAFFIC CONTROL EQUIPMENT DEVICE RECORD REPORT (HISTORY OF DEVICE)

DEVICE SERIAL NUMBER	DEVICE NAME	DEVICE MODEL NUMBER	MFG. CODE	LOC. CODE	LOCATION	INSTALLED	REMOVE
2345	CCT	2 Ø	123	1234	Lombard & Greene	01/22/82	03/23/8
2345	CCT	2 Ø	123	1111	SHOP - REPAIR	03/23/82	03/25/8
2345	CCT	2 Ø	123	1110	SHOP - STOCK	03/25/82	03/27/8
2345	CCT	2 Ø	123	1222	Baltmore & Pratt	03/27/82	
3456	GCM	3 Ø	233	1234	Lombard & Greene	01/10/82	02/10/8
3456	GCM	3 Ø	233	1000	THEFT	02/10/82	
3455	GCM	3 Ø	234	1001	SHOP - REPAIR	02/10/82	02/11/8
3455	GCM	3 Ø	234	1002	SCRAPPED	02/11/82	

FIGURE 37 Baltimore's device-record report (history of device).

Subsystem	Subsystem MTBF	No. of Units	UTCS MTBF
Vehicle Detector	104,600 hrs.	497	210 hrs.
Controller	57,500	111	518
Power Supply (field)	1,295,000	111	11,700
Central Communications	472	1	472
Computer	157	1	157
Display	501	1	501
Telephone Lines	303	1	303
Overall System			49

DETECTION SYSTEM FAILURES

4	Loops
66	Detector
41	Communications
111	Failures in 23,328 hrs.

CONTROLLER SYSTEM FAILURES

15	Controller
13	Adapter Unit
17	Communications
45	Failures in 23,328 hrs.

CENTRAL COMMUNICATIONS FAILURES

1	Dual Amplifier
10	2FS Receiver
3	3FS Transmitter
3	Power Supply
17	Failures in 8,016 hrs.

COMPUTER FAILURES

6	CPU
12	Disk
2	Interface Unit
17	Magnetic Tape
8	Line Printer
5	Card Reader
1	TTY
51	Failures in 8,016 hrs.

FIGURE 38 Values of MTBF for the UTCS project in Washington, D.C.

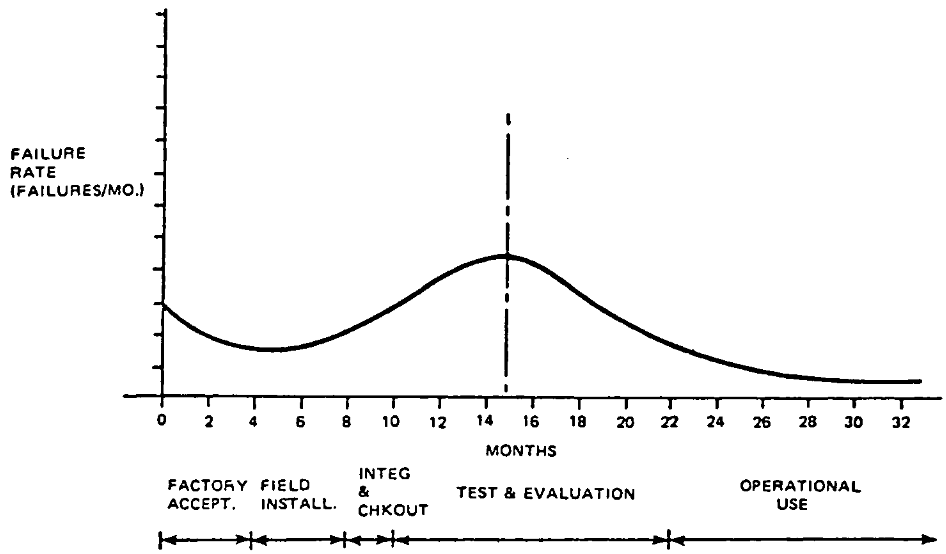


FIGURE 39 Generalized historical profile of failures of system hardware.

(MTBF) and the mean time to repair (MTTR). The FHWA's *Computerized Signal System* notebook (*78*) provides an example:

> If an item of equipment has an MTBF of 10,000 hours and there are 100 of these items installed in the system, the MTBF of the entire set of equipment will be 100 hours:

$$\text{System MTBF} \doteq \frac{\text{Unit MTBF}}{\text{No. of Units}} = \frac{10{,}000}{100} = 100 \text{ hr}$$

> Even conservatively dividing this number by two produces an MTBF of 50 hours which would appear to justify only one or two spare parts. If, however, repair of the item requires two weeks because it is being returned to the factory for repairs, more spare parts should be kept on hand. Note that the 50 hours of operation refers to seven-day weeks with 24-hour days. Thus an MTBF of 50 hours refers to only two days of operation between failures. During a two-week repair period, seven components could fail.

Intersection Availability as a Measure of Reliability

Cimento defines the availability of an intersection as the percentage of the time that an intersection is able to operate in its intended mode (rather than a back-up mode). It is calculated from component failure rates and equipment repair time. He points out that this measure is useful because it

1. Describes reliability in terms perceived by the system user (the motorist);
2. Normalizes the system as to size, that is, a 25-intersection system can be compared to a 200-intersection system; and
3. Allows systems with different architectures and equipment approaches to be readily compared.

Table 18 gives in terms of intersection availability some of the results of a communication trade-off study reported by Cimento. The table points up one of the major assets of a distributed system over a centralized architecture.

Other Measures of Reliability

The concept of Mean Time of Existence (MTOE) of failure is used in the United Kingdom and was discussed in Chapter 2.

FISCAL CONTROLS

The subject of fiscal controls includes, in addition to routine considerations of cost accounting, budgeting, invoices, and payroll, some interesting points regarding equipment-replacement programs.

Robinson, Sanderlin & Associates pointed out (*49*) that operational obsolescence occurs when the equipment reaches an age (of about 12 years) when significant maintenance and operational difficulties may reasonably be expected. Technological

TABLE 18

COMPARISON OF INTERSECTION AVAILABILITY[a]

	Central Computer[b]		Distributed Processing[c]
	FDM[d]	TDM[e]	TDM
Intersection Availability (fraction of time)	0.997	0.997	0.999
Intersection Down Time/Year (hours)	23.1	23.0	2.3

[a]Adapted from Reference 40.
[b]Based on electromechanical controllers and owned cable.
[c]Based on microprocessor controllers and owned cable.
[d]Frequency division multiplexing.
[e]Time division multiplexing.

obsolescence occurs sooner, typically within 2 to 10 years, when major technological advances have caused equipment in use to be significantly less flexible than the new models on the market. Because of the advances, it may be difficult to purchase replacement parts, including chips. Determinations of MTBF and MTTR can be used to assign priorities for replacement of equipment that fails frequently.

Every traffic unit needs to be in a position to budget funds to replace operationally and technologically obsolete traffic signals. These funds for modernization cannot come in a sudden burst of zeal, because manpower limitations prevent absorption of a brief influx of such funds. Instead, the program must be steady, on a planned basis, to replace a certain percentage of the equipment each year.

CHAPTER EIGHT

CONCLUSIONS

The key conclusions to be drawn from this synthesis are as follows:

- Evidence abounds from U.S. sources and those abroad that signal malfunctions are widespread and serious in their consequences. The problem lies not only in the frequency of failures but also in excessive time before a failure may be reported. There are serious impacts on equipment life, road-user costs of additional stops and delay, safety, fuel consumption, and pollutant emission.
- Maintenance personnel and their supervisors should be aware of their legal responsibility and liability.
- The cost-effectiveness of good maintenance is beyond question. Even if signal malfunctions were to increase stops and delay by just a small percentage and a second or two, respectively, the cost to motorists would far exceed the costs reported herein to maintain the signals properly.
- Specific problem areas include nonstandardization of equipment, use of sophisticated equipment beyond the capability of maintenance personnel, over use of sophisticated detector/controller schemes, inadequate inspection during installation, the use of low-grade components not suitable to the environment, insufficient quality control, damage from power surges including lightning transients, and lack of funds for equipment-replacement programs.
- Ways to reduce maintenance needs or to make required maintenance easier to perform include the drafting of tighter specifications, which should include requiring components with higher reliability and demanding modularity of components. Stringent acceptance testing should go hand in hand with tight specifications.
- Technical control of the maintenance work should rest directly with that part of the organization responsible for signal operations.
- Routine, scheduled maintenance no longer is concerned primarily with preventive measures. Rather, the emphasis is on inspection patrols, and self-detection methods, to discover malfunctions, and on the subsequent checking to be certain that the faults have been corrected.
- Group relamping is cost-effective, and many agencies use a one-year replacement cycle.
- The evolution from electromechanical to solid-state designs has caused a corresponding transition in the requirements for maintenance personnel. Electronics technicians are replacing electricians.
- Microprocessor-based diagnostic equipment is now available for use in both field and shop.
- Maintenance contracts may be cost-effective and practical in high-density areas, and may be necessary for computers and much of the peripheral equipment.
- Maintenance-call rates, person-hours, and dollar costs are now quite well known. Microprocessor-based equipment is more reliable than earlier technologies because of fewer components and connection points.
- The number of signalized intersections (including school flashers and flashing beacons) that can be maintained by one technician varies widely but seems typically to be in the range of 25 to 35.
- Agencies that have stringent acceptance testing report an excellent record of mean time between failures of their accepted controllers.
- Maintenance capabilities need to be upgraded through training programs for existing personnel, attraction and retention of appropriate personnel, and the use of contract maintenance.
- The maintainability of the controller/detector scheme needs to be improved by simplifying designs, enforcing standardization and interchangeability, and insisting on rigorous inspection and acceptance testing.

REFERENCES

1. Ringle, K, "D.C. Stoplights: Halt, Lame and a Pain to Maintain," *The Washington Post* (Sunday, March 27, 1983) p. A1.
2. Highway Research Board, *NCHRP Synthesis of Highway Practice 22: Maintenance Management of Traffic Signal Equipment and Systems.* Highway Research Board, Washington, D.C. (1974) 41 pp.
3. International Municipal Signal Association, Inc., *Traffic Signal Manual of Installation and Maintenance Procedures,* 2nd ed., Fort Worth, Texas (1981).
4. Institute of Transportation Engineers, "Traffic Signal System Definitions, 1978," Recommended Practice RP-8, Washington, D.C. (1978).
5. Federal Highway Administration, *Traffic Control Systems Handbook.* Implementation Package 76-10, Washington, D.C. (June 1976).
6. Thomas, J. M., Chief, Div. of Traffic Engineering, City of Atlanta, Memorandum dated February 22, 1982 on Status of Traffic Engineering Field Facilities, unpublished, 2 pp.
7. Rowe, S. E., "Efficiency and Reliability of Traffic Signal Systems." Department of Transportation, City of Los Angeles, unpublished (August 1981) 5 pp.
8. Cobbe, B. M. and G. Ridley, "Traffic Signals," *The Journal of the Institution of Highway Engineers.* London, England, (May 1970) pp. 81–87.
9. Hulscher, F. R., "Reliability Aspects of Road Traffic Control Signals," *Traffic Engineering & Control* (March 1977) pp. 98–102.
10. Tillotson, H. T., "Delays Caused by Traffic Signal Failures," *Traffic Engineering & Control* (Oct. 1975) pp. 420–422.
11. Benioff, B. and T. Rorabaugh, *A Study of Clearance Intervals, Flashing Operation, and Left-Turn Phasing at Traffic Signals.* Report FHWA-RD-78-48, Federal Highway Administration, Offices of Research & Development, Washington, D.C. (May 1980) 64 pp.
12. MacGowan, J. and J. Eicher, "Operations and Maintenance Are as Important as Traffic Performance," *CCSAG Newsletter.* Institute of Transportation Engineers, Washington, D.C. (June 1978) p. 6.
13. Edwards and Kelcey, Inc., *Maintenance of Traffic Signal Systems.* Prepared in October, 1981 for the Pennsylvania D.O.T. Revised by PennDOT for final printing in December, 1982, 116 p. [For an account of selected portions of this report see Kraft, W. H. and J. R. Doughty, "Traffic Signal Maintenance Requirements," ASCE Preprint 82-058, Conference at Las Vegas, Nevada (April 26–30, 1982) 10 pp.]
14. Tarnoff, P. J. and P. S. Parsonson, *NCHRP Report 233: Selecting Traffic Signal Control of Individual Intersections.* Transportation Research Board, Washington, D.C. (1981) pp. 37–46.
15. Carlson, W., "How Do You Keep Your Traffic Signals Working?" *IMSA Signal Magazine* (July–August 1976) p. 10.
16. Ernest, H., "Highway Risk Management: Traffic Control Devices," *ITE Journal* (Jan. 1980) pp. 18–21.
17. Fischler, A. J., "Legal Signs for Traffic Signals," *IMSA Signal Magazine* (Jan.–Feb. 1978) pp. 11, 23.
18. Krueper, H. J., "Legal Liabilities Pertaining to Traffic Signal Maintenance and Operations," *IMSA Signal Magazine* (March–April 1976) pp. 7–8.
19. Pivnik, S. I., "The Law and Traffic Control," *Traffic Engineering* (Feb. 1977) pp. 35–38.
20. Vance, J. C., "Personal Liability of State Highway Department Offices and Employees," *NCHRP Research Results Digest 79.* Transportation Research Board, Washington, D.C. (Sept. 1975) 26 pp.
21. Fischler, A. J., "The Washington Spectrum," *IMSA Signal Magazine* (May–June 1978) pp. 10, 19.
22. Fischler, A. J., "The Washington Spectrum," *IMSA Signal Magazine* (July–Aug. 1978) pp. 18, 27.
23. Thomas, L. W., "Legal Implications of Highway Department's Failure to Comply with Design, Safety, or Maintenance Guidelines," *NCHRP Research Results Digest 129.* Transportation Research Board, Washington, D.C. (Oct. 1981) 17 pp.
24. Institute of Transportation Engineers, *Traffic Improvements—Legal Aspects and Liability.* Notebook for one-day seminar. Publication PD-2, Washington, D.C., no date.
25. Lewis, R. M., *NCHRP Synthesis of Highway Practice 106: Practical Guidelines for Minimizing Tort Liability.* Transportation Research Board, Washington, D.C. (1984) 40 pp.
26. Scheck, D. E., "Traffic Signal Diagnostic Equipment and Preventative Maintenance Procedures," Ohio DOT, FHWA Report No. FHWA/OH-81/002 (March 1981) 149 pp.
27. New York State D.O.T., Memorandum from D. J. Russo of Traffic and Safety to B. B. MacDonald, entitled Traffic Signal Preventive Maintenance Effort," File 155-3, Albany, N.Y. (May 10, 1976) 2 pp.
28. New York State D.O.T., Memorandum from D. J. Russo of Traffic and Safety to P. S. Parsonson of Georgia Tech, file 155-23, Albany, N.Y. (Jan. 9, 1984) 1 p.
29. Parsonson, P. S. and P. T. Tarnoff, "Maintenance Costs of Traffic Signals," *Record 737.* Transportation Research Board, Washington, D.C. (1979) pp. 24–30.
30. Econolite, "Traffic Control Application Information," Manual No. 1, Sections entitled Type F Controller Instructions (no date, ca. 1959).
31. Crouse Hinds Company, "Instructions for Installing, Op-

erating and Maintaining the PCE-PCEM Synchronous Expansive Traffic Controller System," Technical Data Bulletin 72T, Syracuse, New York (1962) 31 pp.

32. Farrell, W., "Maintenance Neglected But Not Forgotten," *IMSA Journal* (Jan.-Feb. 1982) p. 16.
33. National Advisory Committee on Uniform Traffic Control Devices, *Traffic Control Devices—An Operating Guide.* U.S. DOT, Federal Highway Administration, Washington, D.C. (1975).
34. Federal Highway Administration, *Highway Safety Program Manual, Volume 13, Traffic Engineering Services* (Traffic Control Devices), Washington, D.C. (1976) 76 pp.
35. Chamberlain, G. M., "Traffic Signals Come of Age," *The American City* (Aug. 1971) pp. 93–94, 112.
36. Souder, A. M., "Polycarbonate Signal Heads—Status Update," *ITE Journal* (April 1982) pp. 28–29.
37. Mitchell, M. E., "The Key to Preventive Maintenance on a Traffic Signal System," *Traffic Engineering* (Nov. 1975) pp. 30–31.
38. Tindale, S. A., "Tampa's Lamp Maintenance Program," *Traffic Engineering* (Nov. 1976) pp. 39–41.
39. Cimento, A. A., "Traffic Control Systems Hardware," *IEEE Transactions on Vehicle Technology,* Vol. VT-29, No. 2 (May 1980) pp. 106–124.
40. Ficklin, N., "The Memphis Computerized Signal System," *Proceedings of the 1981 Engineering Foundation Conference on Issues in Control of Urban Traffic Systems.* New England College, Henniker, New Hampshire (June 28–July 3, 1981) pp. 15–24.
41. Lewis, R. A., "Overland Park's Traffic Control System Experience," *Proceedings of the 1981 Engineering Foundation Conference on Issues in Control of Urban Traffic Systems.* New England College, Henniker, New Hampshire (June 28–July 3, 1981) pp. 187–191.
42. Bigelow, R. P., *Guide to Negotiating a Computer Contract,* 1975, abridged and updated in *Computer Contract Checklist,* Callaghan & Co. (1975).
43. Tarnoff, P., "Control Systems for Smaller Communities," *Proceedings of the 1981 Engineering Foundation Conference on Issues in Control of Urban Traffic Systems.* New England College, Henniker, New Hampshire (June 28–July 3, 1981) pp. 245–248.
44. Rowe, S. E., "Management of Traffic Signal Systems in Los Angeles." Presentation to the Transportation Research Board, Conference Session on Cost-Effective Management of Traffic Control Systems, unpublished, 62nd Annual Meeting, Washington, D.C. (Jan. 20, 1983).
45. Blase, J. H., "Computer Aids to Large-Scale Traffic Signal Maintenance," *Traffic Engineering and Control* (July 1979) pp. 341–347.
46. Thomas, J. M., Jr., "Closed-Loop On-Street Traffic Control Systems." Advanced Traffic Engineering Seminar, Georgia Division of the Southern Section, ITE, Cobb County, Georgia (Oct. 1981) 13 pp.
47. Blanks, H. S., L. W. Davies, F. R. Hulscher, and J. W. Syme, "Failsafe Requirements of Road Traffic Signal Equipment," *Australian Road Research Board Proceedings.* Vol. 8 (1976) pp. 27–35.
48. Conway, E. F., Report of a Study to Determine Proper Staffing for Fulton County's Traffic Signal Shop (Aug. 1983) 5 pp., unpublished.
49. Robinson, Sanderlin & Associates, *Feasibility Study for Central Control Traffic Signal System,* City of Macon, Georgia (Nov. 1981) pp. 25–27.
50. Stout, T. L., J. H. Kell, J. L. Kay, R. D. Henry and C. M. Abrams, *An Approach for Selecting Traffic Control Systems.* Final Report for NCHRP Project 3-18(3). Transportation Research Board, Washington, D.C. (March 1977) 235 pp. plus appendixes.
51. Gibson, D. R. P., "Status Report on the Type 170 Traffic Signal Controller System." Federal Highway Administration, Office of Implementation, Washington, D.C. (Oct. 1982) 16 pp.
52. Mazuryk, R. J., *Operations Manual for Isolated Traffic-Actuated Intersections,* Model 170, Microcomputer Manual, ITAP—Rev. 4, New York State DOT, Traffic and Safety Division (Jan. 1982) 149 pp.
53. New York State DOT, Traffic and Safety Division, *Laboratory Diagnostics Manual, Traffic Signal Microcomputer—Model 170,* no date, 17 pp.
54. Federal Highway Administration, *Type 170 Traffic Signal Controller System—Hardware Specification.* FHWA-IP-78-16 (Dec. 1978).
55. LFE Corporation, "19 Tips on Maintenance." Traffic Control Division, Automatic Signal, Norwalk, Conn. (1979) 7 pp.
56. National Electrical Manufacturers' Association, *Standards Publication No. TS-1, 1983,* Washington, D.C. (1983).
57. "Ailing Traffic Signals Get Emergency Van 'House Call'," *Rural and Urban Roads* (Jan. 1979) pp. 46–47.
58. Staunton, M. M., *Signal Controller Operation Recording Equipment (SCORE).* An Foras Forbartha, Dublin, Ireland (May 1978) Report No. RT 179, 55 pp. (Available from NTIS as Report No. PB81-124117.)
59. Staunton, M. M., *Side Tone Unit—A Simple Device for Checking Traffic Detectors and Signal Equipment.* An Foras Forbartha, Dublin, Ireland (Feb. 1981) 6 pp.
60. Goldenberg, H. and A. Greenwald, "Model 170 User's Guide," Traffic and Safety Division, New York State DOT (Dec. 1980) p. iii.
61. New York State Department of Transportation, Division of Traffic and Safety, *Safety with Traffic Technology; Microcomputer Specifications* (Nov. 1976) pp. 1–17.
62. Federal Highway Administration, *Manual on Uniform Traffic Control Devices.* U.S. DOT, Washington, D.C. (1978).
63. Farrell, W., "Something to Think About," *IMSA Journal* (May–June 1981) pp. 15, 25.
64. Venable, C. A., "Contracting Out Traffic Signal Maintenance," *American Transportation Builder* (Summer 1983) pp. 13–14.
65. Federal Highway Administration, *Management of Traffic Control Systems.* Participant Notebook and Instructor's Notebook, Washington, D.C. (no date, ca. 1977).
66. Stanford, M. R. and H. Parker, "The South Bay Traffic Signal Control System," *Traffic Engineering,* Vol. 47, No. 4 (April 1977) pp. 28–35.
67. Burmeister, D. L. and P. S. Parsonson, "Installation Innovations for Environmental Protection of Inductive Loops," *Compendium of Technical Papers,* Institute of Transportation Engineers 49th Annual Meeting, Toronto (Sept. 23–27, 1979) pp. 238–242.

68. Waight, V. H., "Designing with Maintenance in Mind," *Traffic Engineering* (May 1976) pp. 26–28.
69. Canoga Controls Corporation, *Manual for 400 Series Digital Loop Detectors* (revised Aug. 1977) p. 4-2.
70. Tindale, S. A., "Solid-State Traffic System Battles Environment," *Traffic Engineering* (Dec. 1975) pp. 21–23.
71. Infurchia, N., "Lightning Protection for Traffic Controllers through Stringent Ground Bonding," *Traffic Engineering* (Feb. 1972) pp. 34–35.
72. Newton, T., Presentation to Transportation Engineering Training Program, Arizona DOT facility, Phoenix (Sept. 13, 1983).
73. McDonnell, R. M., "Preventive Maintenance Can Work for You," *Municipal Signal Engineer,* Vol. 25, No. 2 (March–April 1960) pp. 17–22.
74. National Advisory Committee on Uniform Traffic Control Devices, *Traffic Control Devices Handbook.* U.S. D.O.T., Federal Highway Administration, Washington, D.C. (1983).
75. Bikowitz, E. W. and S. P. Ross, *Installation of Vehicle Detector Loops,* Special Report 75, Report FHWA/N7/SR-83/75, Engineering Research and Development Bureau, New York State D.O.T., Albany (July 1983) 12 pp. plus appendixes.
76. Federal Highway Administration, *Traffic Detector Handbook,* Implementation Package FHWA-IP-83-2, Washington, D.C. (July 1983) 276 pp.
77. City of Baltimore, Department of Transit and Traffic, *Microcomputer-Based Traffic Signal Equipment Inventory System* (Jan. 27, 1983).
78. Federal Highway Administration, *Computerized Signal Systems.* Student Workbook and Instructor's Guide, Washington, D.C. (1979).

BIBLIOGRAPHY

GENERAL REFERENCES

California DOT, Sacramento, "The Inductive Loop Vehicle Detector; Installation Acceptance Criteria and Maintenance Techniques" by J. W. Ingram, prepared for the FHWA, Washington, D.C. (March 1976) 24 pp. (Available from NTIS, Stock No. PB-263 948.)

Huddart, K. M., "Experience in New Arrangements for Traffic Signal Maintenance." Planning and Transport Research and Computation Co., Ltd., London, PTRC Summer Annual Meeting (July 8–12, 1974) University of Warwick.

Meno, F. J., II, "Economical Maintenance of Traffic Signal Systems," *Traffic Engineering* (Feb. 1953) pp. 157–158.

Oppenlander, J. C. and T. G. Smith, "Scheduling Traffic Signal Maintenance," *Engineering Bulletin of Purdue University* (1966).

Rach, L., "Traffic Signals," *Transportation and Traffic Engineering Handbook*, 2nd ed., Institute of Transportation Engineers, Washington, D.C. (1982) pp. 750–751.

Riedel, C. E., *Signal Installation Manual*, New York State DOT, Traffic and Safety Division (Sept. 1981) 104 pp.

Upham, C. M., Jr., "The Key to Extending the Life of Your Traffic Controllers," *Municipal Signal Engineer* (Nov./Dec. 1964) pp. 30–31.

LAMP STANDARDS AND SCHEDULED REPLACEMENT

Hulscher, F. R., "Practical Implementation of Performance Objective for Traffic Light Signals," *Proceedings, Australian Road Research Board Conference*, 7, Part 5 (1974).

Mann, W. H., "Signal Maintenance," *Traffic Engineering* (April 1959) p. 43.

Ponce, E., "Lamp Study." IMSA Meeting, Bellevue, Washington (1981) 8 p. handout, unpublished.

Smith, T. G. and J. C. Oppenlander, "Economic Model for the Maintenance of Traffic Signals," *Record No. 254*. Highway Research Board, Washington, D.C. (1968) pp. 38–58.

Wares, J. G., "Traffic Signal Lamp Performance," *IMSA Signal Magazine*, Vol. 6, No. 2 (1970) pp. 27, 30.

LIABILITY

Pivnik, S. I., "Changing Attitudes Toward Governmental Immunity to Lawsuits and Assignment of Liability Relative to Traffic Control Devices," *IMSA Signal Magazine* (Jan.–Feb. 1977) pp. 8, 21.

Thomas, L. W., "Liability of State and Local Governments for Negligence Arising Out of the Installation and Maintenance of Warning Signs, Traffic Lights and Pavement Markings," *NCHRP Research Results Digest 110*. Transportation Research Board, Washington, D.C. (April 1979) 14 pp.

Thomas, L. W., "Liability of State Highway Departments for Design, Construction and Maintenance Defects," *NCHRP Research Results Digest 80*. Transportation Research Board, Washington, D.C. (Sept. 1975).

COMPUTERIZED PROGRAM MANAGEMENT AND FAULT DETECTION

Cass, S., "Toronto's Digital Computer Signal System," *Traffic Engineering and Control* (Jan. 1981) pp. 460–463.

Parapar, S. M., "Computerized Reporting for Traffic Signal Maintenance," *Traffic Engineering* (July 1973) pp. 47–50.

Randolph, D. A. and T. K. Datta, "Countywide Traffic Signal Maintenance Program," *Record No. 727*. Transportation Research Board, Washington, D.C. (1979) pp. 44–50.

Sperry Systems Management Division, *Urban Traffic Control and Bus Priority System Operations and Maintenance*. FHWA Report No. FHWA-RD-76-160 (June 1976) 181 pp.

Stemmler, R., D. Scheck, S. Kapka, and L. T. Hon, *Determination of Optimum Inventory Levels and Storage Centers for Traffic Signal Materials*. Ohio Department of Transportation, Final Report (June 30, 1974).

Traffic Planning Associates, Inc., *Expansion of Atlanta Traffic Data Acquisition and Control System*, Technical Report (July 1976) pp. 114–119.

Waterman, D. W., "Maintenance and Inventory Recordkeeping," presented at seminar entitled "Microcomputer Applications in Transportation Engineering" at ITE 1982 Annual Meeting, Chicago (Aug. 26, 1982) 9 pp.

Wilshire, R. L., "The Benefits of Computer Traffic Control," *Traffic Engineering* (April 1969) pp. 14–19.

ELECTRONIC TROUBLESHOOTING, DIAGNOSTIC EQUIPMENT

"Acceptance Test Manual—Model 170 Traffic Signal Control Equipment." Federal Highway Administration, Office of Implementation (May 1983).

Baltayan, A. M., "Troubleshooting Solid State Traffic Control Equipment," *IMSA Signal Magazine*, Vol. 7, No. 3 (May 1972) pp. 12–13.

"Maintenance Guidelines—Model 170 Traffic Signal Control Equipment." Federal Highway Administration, Office of Implementation (May 1983).

LIGHTNING PROTECTION

Addy, R. E., "Lightning Phenomena," presented at IMSA Annual Meeting, New Orleans (1973) 23 pp.

Barksdale, C. B., "Gas Tube Broadens Plant Protection," *Telephone Engineer and Management* (February 15, 1972) pp. 70–71.

Barksdale, C. B., "New Gas Tube Protector for Circuits," *Telephony* (Oct. 17, 1970).

Bodle, D. W., "Characterization of Lightning Surges in Telecommunication Plant." Joslyn Electronic Systems, Goleta, Calif. (1972) 7 pp.

Bodle, D. W., "Relationship of Grounding and Bonding to the Effectiveness of Lightning Protection Devices." IEEE Conference Record of FGA (Oct. 1970) pp. 323–327.

Clarkson, G. A. and F. G. Scudner, "Surge Protection of Telecommunications Equipment," *Telecommunications,* Vol. 14, No. 7 (July 1980).

Clarkson, G. A., "Protection: Prescriptions for an Old Surging Headache," *Telephony,* 3-part series, (February 12, 1979) pp. 24–29, (February 19, 1979) pp. 86–88, (March 5, 1979) pp. 34–36.

Edco Company, "Over Voltage Surge Protection for Traffic Devices." Belleview, Fla. (1981) 7 pp.

Joslyn Electronic Systems, "When Lightning Strikes." Goleta, Calif. (1971) 34 pp.

Kahl, F. A., "Lightning Protection ... IMSA Style." 78th IMSA Annual International Conference, New Orleans (August 13, 1973) 22 pp.

Kahl, F. A., "Transient Protection for Signalling and Communication Equipment—A New Approach," AAR Comm. and Signal Meeting, Dallas, Texas (Oct. 1–3, 1968) 16 pp.

APPENDIX A

PREVENTIVE MAINTENANCE CHECKLISTS AND MANPOWER REQUIREMENTS FOR TYPICAL INTERSECTIONS

This appendix includes sample forms for recording preventive-maintenance work. See Appendix B for other types of maintenance forms.

The material from Pennsylvania was obtained from the Edwards and Kelcey report for the Pennsylvania DOT (13). The times shown in the right margin are labeled M for minutes and H for hours. They are times per unit or per channel of detection. Users may wish to clip off the time estimates before using the form.

The forms from Atlanta are used in the city's signal inventory and preventive-maintenance program. The first two forms are McBee Keysort forms. The next two are for inspection and preventive maintenance of controller and other components. The last form is used in the cleaning/relamping and painting program.

The maintenance form and sample entries from Virginia Beach were provided by John W. Herzke, Traffic Engineer for the city.

PENNSYLVANIA

PREVENTIVE MAINTENANCE RECORD

FOR THE INTERSECTION OF ______________ & ______________

	DATE	LEVEL OF MAINTENANCE	MAINTENANCE PERFORMED – RECOMMENDED INTERVAL IN MONTHS 3	6	9	12	3	6	9	12	
MECHANICAL											
CABINET /PER UNIT											
o paint		A									3H
o oil hinges and lock		A									5M
o clean filter		A									2M
o replace filter		B									2M
o check weatherproof seal (gasket)		A									2M
o check anchor bolts		A									2M
o check for gas, water accumulation, duct sealant		B									2M
o check ground rod clamp		A									1M
o wiring schematics and report available and signed		A									1M
o check operation of fan and heater		A									2M
SIGNAL HEADS /PER UNIT											
o paint exterior of signal		A									1H
o clean lenses, signs and reflectors		B									10M
o replace lamps		B									2M
o check alignment		B									5M
o check for wear on the span wire and the signal wire; check the mechanical hardware (clevis pin, clamps)		A									3M
o check mast arms: free swinging signals - check clevis and the chain		A									3M
o check for cracks or rust in the hardware		A									2M
o check bent hoods, wing nuts, hinges		A									2M
o replace any parts not up to standard		A									2M
o											
o check locking ring (surface); install proper locking devices as required		A									5M
o perform a nighttime check for visibility /per appr		A									10M

	DATE	LEVEL OF MAINTENANCE	MAINTENANCE PERFORMED – RECOMMENDED INTERVAL IN MONTHS 3	6	9	12	3	6	9	12	
MAST ARMS AND POLES /PER UNIT											
o paint		A									8H
o inspect for rust and spot paint as required		A									8M
o inspect the joints for rust and cracks - at arm/upright location - at base plate		A									5M
o inspect anchor bolts for rust and tightness		A									5M
o inspect the horizontal and vertical angle of the arm		A									2M
SPAN WIRE AND POLES/PER UNIT											
o refer to applicable pole section											
o check span wire		A									10M
o check clamps, hardware		A									5M
o check guy wire and the anchor		A									5M
PUSH BUTTONS /PER UNIT											
o check push button on each end of actuated crosswalks and visually verify pedestrian signal operation; verify timing		B									5M
o check push button lamp (if exists) for operation		B									2M
o check push button signs and clean if necessary		B									5M
o check push button signs alignment		B									3M
DETECTOR SENSORS /PER SENSOR											
o make a visual inspection of the roadway along the saw cut for exposed wires, cracks, potholes, etc.		A									5M
o check alignment for sonic, magnetic and radar type detectors		A									5M
o check anchorage for pressure detector frame		A									2M

	Date	Level of Maintenance	3	6	9	12	3	6	9	12
			Maintenance Performed — Recommended Interval in Months							
UNDERGROUND										
JUNCTION BOXES AND HANDHOLES /PER UNIT										
o check the integrity of the splices		A								
o check the ground rod and clamp connection, and bonding of conduits		A								
o check the insulation		A								
o check for abnormal amount of water		A								
o check lid for abnormal condition and fit		A								
ELECTRICAL										
o check radio interference filter and lightning arrestor		A								
ELECTROMECHANICAL CONTROL EQUIPMENT										
Dial Assembly										
o check for wear on key follower		B								
o check for burned or pitted contacts and service contacts per manufacturer maintenance recommendations		B								
o check for key positions		B								
o check for cycle gear size and mesh		B								
o check dial motor operation		B								
o check all dials according to manufacturer's recommendations		B								
o if controller is part of a system, test offset		B								
o check duration of the advance pulse		B								
Cam Assembly										
o check for end play		B								
o clean and lubricate as required by manufacturer		B								
o visually inspect for abnormal wear or cracks		B								
o visually inspect contacts for pitting/discoloration and service contacts per manufacturer maintenance recommendations		B								

	Date	Level of Maintenance	3	6	9	12	3	6	9	12
			Maintenance Performed — Recommended Interval in Months							
o check spring tension on contacts		B								
o check for any loose wiring contacts		B								
o check for operation of advancing mechanism to conform with manufacturer's requirement		B								
o check if all connections are secure and tight		B								
o visually inspect wires for wear, rubbing, deterioration of insulation		B								
o										
Relays										
o check for burned and pitted contacts and service contacts per manufacturer's maintenance recommendations		B								
o check for tight and secure fit into the sockets		B								
o if latch type relays check for latch operation as per manufacturer's recommendations		B								
Flashers										
o check flash rate		B								
o check operation		B								
o service contacts per manufacturer's recommendation		B								
o check for tight and secure fit into sockets		B								
Switches										
o verify operation of each switch position		B								
Terminal Connections										
o check visually for signs of corrosion or any abnormal condition		B								
o tighten all terminal connections		B								

	DATE	LEVEL OF MAINTENANCE	3	6	9	12	3	6	9	12	
			MAINTENANCE PERFORMED								
			RECOMMENDED INTERVAL IN MONTHS								
Conflict Monitor											
o refer to solid state section											
Detector Amplifiers											
o refer to solid state section											
SOLID STATE, ANALOG, AND MICROPROCESSOR BASED CONTROL EQUIPMENT/PER UNIT											
o check if the time settings match the master time sheet		B									5M
o check if all indicator lamps on the modules are working; replace failed lamps		A									5M
o check for extension by detector actuation		B									10M
o check if the modules are fitting tight and secure into the frame		B									2M
o check if the connector is tight and secure		B									3M
o											
Load Switches / Per Unit Controller											
o check if load switch packs are fitting tight and secure into the chassis		B									5M
Conflict Monitor / Per Unit											
o jump two conflicting green phases and check if conflict monitor responds; if it does, check if stop timing is implemented		B									5M
o if auxiliary logic package exists in the controller, check if conflict monitor detects a 24 VDC level drop		B									3M
o check if flash is activated		B									2M
Flashers											
o refer to electromechanical section											5M
Switches											
o refer to electromechanical section											5M

	DATE	LEVEL OF MAINTENANCE	3	6	9	12	3	6	9	12	
			MAINTENANCE PERFORMED								
			RECOMMENDED INTERVAL IN MONTHS								
Terminal Connections											
o refer to electromechanical section											5M
Relays											
o refer to electromechanical section											10M
Auxiliary Logic / Per Unit											
o check to ensure that the points of connection are making good contact		B									5M
o if electromechanical device, check for any wear; if contacts are used, cleaning may be required per manufacturer's recommendations		B									10M
Detector Amplifiers / Per Channel											
o check if the detector is detecting vehicles within its design zone of detection		A									15M
o tune the detector if necessary		A									3M
o check if the connectors are tight and secure		A									2M

	DATE	LEVEL OF MAINTENANCE	MAINTENANCE PERFORMED — RECOMMENDED INTERVAL IN MONTHS: 3	6	9	12	3	6	9	12	
INTERCONNECTED EQUIPMENT/PER UNIT											
o check if controller operates in the mode selected by the supervisory master		B									5M
o disconnect from the master supervisory system and check for "free" or backup operation		B									10M
o check any special equipment per manufacturer's recommendations		B									
GENERAL											
o record all changes in: timing, wiring, or any function											
o periodically check the electric bill for leaky insulation											
SIGNATURE OF SIGNAL MECHANIC PERFORMING PREVENTIVE MAINTENANCE											

PREVENTIVE MAINTENANCE RECORD CODES

Code	Description
N	No maintenance function performed
C	Maintenance check or inspection performed with no anticipated problems - service at next regular interval
P	Possible problem - schedule additional Preventive Maintenance
I	Intermittent problem - schedule additional inspection or maintenance

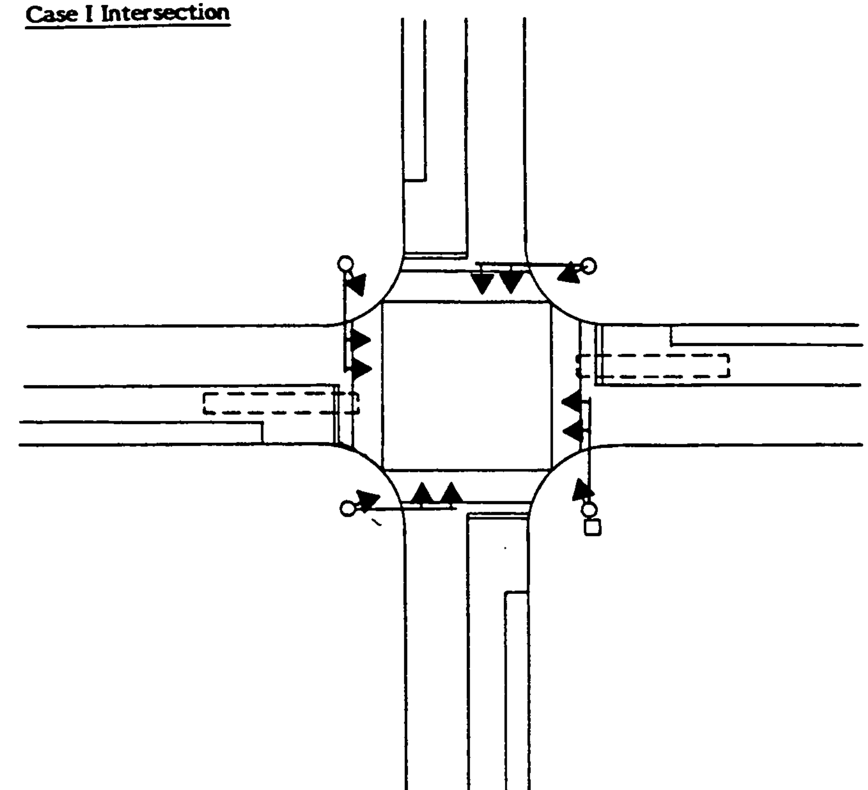
PREVENTIVE MAINTENANCE RECORD

FOR THE INTERSECTION OF Main St. & Henderson

MECHANICAL	LEVEL OF MAINTENANCE	MAINTENANCE PERFORMED — RECOMMENDED INTERVAL IN MONTHS: 3	6	9	12	3	6	9	12	
DATE		1-5-81	4-5-81	7-6-81	10-5-81					
CABINET /PER UNIT										
o paint	A									3H
o oil hinges and lock	A				N					5M
o clean filter	A		N		N					2M
o replace filter	B				C					2M
o check weatherproof seal (gasket)	A				N					2M
o check anchor bolts	A				N					2M
o check for gas, water accumulation, duct sealant	B				C					2M
o check ground rod clamp	A				N					1M
o wiring schematics and report available and signed	A		C		C					1M
o check operation of fan and heater	A		–		C					2M
SIGNAL HEADS /PER UNIT										
o paint exterior of signal	A									1H
o clean lenses, signs and reflectors	B				C					10M
o replace lamps	B				C					2M
o check alignment	B		P	C	C					5M
o check for wear on the span wire and the signal wire; check the mechanical hardware (clevis pin, clamps)	A		C		C					3M
o check mast arms: free swinging signals - check clevis and the chain	A		C		C					3M
o check for cracks or rust in the hardware	A		N		N					2M
o check bent hoods, wing nuts, hinges	A		C		C					2M
o replace any parts not up to standard	A		N		N					2M
o										
o check locking ring (surface); install proper locking devices as required	A		N		N					5M
o perform a nighttime check for visibility /per appr	A		N		N					10M

ESTIMATED MANPOWER REQUIREMENTS TO PERFORM ANNUAL PREVENTIVE MAINTENANCE FOR TYPICAL INTERSECTIONS

Case I Intersection



Intersection Estimates:

1. 4 approaches
2. 12 signal heads
3. 4 mast arms and standards
4. no pedestrian signals
5. 4 pedestrian push buttons
6. 2 loop detectors
7. 4 junction boxes and hand holes
8. semi-actuated electromechanical controller

Case I Intersection - Time Calculations Based On Time Estimates for Preventive Maintenance

	Months 3	Months 6	Months 12	Years 2-5
Cabinet	—	0:05	0:14	3:00
Signal Heads (12)	—	5:24	2:24	12:00
Nighttime Check (4 Approaches)	—	0:40	—	—
Mast Arm and Poles (4)	—	—	1:20	32:00
Pedestrian Push Buttons (4)	—	1:00	—	—
Junction Boxes and Handholes (4)	—	—	0:40	—
Detector (2 Approaches)				
o loop inspection	0:10	—	—	—
o detector amplifier (2)	0:40	—	—	—
Controller (Electromechanical)	—	—	8:00	—
	0:50	7:09	12:38	47:00
Travel Time*	1:00	1:00	2:00	—
	1:50	8:09	14:38	47:00**

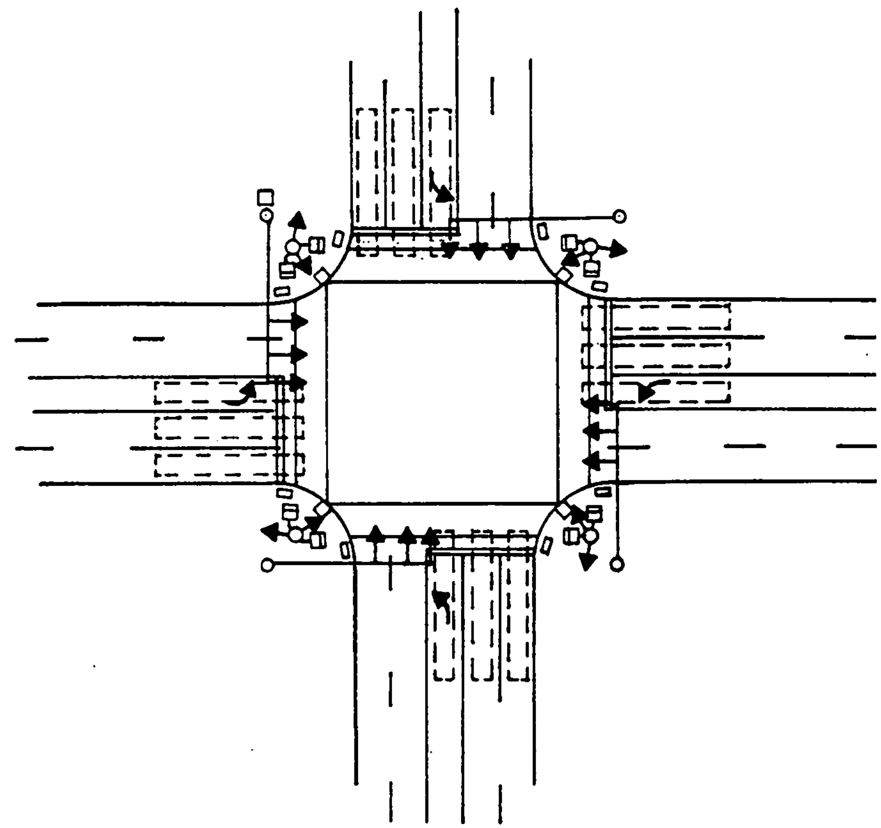
Therefore, per year: (1:50) x 4 + (8:09) x 2 + 14:38
= 38:16 hours

Record Keeping per year 2 hours

Total hours for Preventive Maintenance per year per intersection: 41 hours

*1 hour per 6.5 hours of working time
**2-5 year maintenance time is not included in the yearly time estimates.

Case III Intersection



Intersection Estimates:

1. 4 approaches
2. 20 signal heads
3. 4 mast arms and standards
4. 4 traffic standards for pedestrian signals and push buttons
5. 8 pedestrian signals
6. 8 pedestrian push buttons
7. 12 loop detectors, 3 per approach
8. 8 junction boxes and hand holes
9. solid state volume density controller

Case III Intersection - Time Calculations Based On Time Estimates for Preventive Maintenance

	Months 3	Months 6	Months 12	Years 2-5
Cabinet (1)	—	0:05	0:14	3:00
Signal Heads (28, including pedestrian)	—	12:36	5:36	28:00
Nighttime Check (4 Approaches)	—	0:40	—	—
Mast Arms and Poles (8, including pedestrian)	—	—	2:40	64:00
Pedestrian Push Buttons (8)	—	1:00	—	—
Detector (4 approaches)				
o loop inspection	1:00	—	—	—
o amplifiers ( ) 2 channels/unit	2:40	—	—	—
Junction Boxes and Handholes (8)	—	—	1:20	—
Controller: (Solid State)	—	0:05	0:20	—
Load Switches	—	—	0:05	—
Conflict Monitor	—	—	0:10	—
Flasher	—	—	0:05	—
Switches	—	—	0:05	—
Terminal Connections	—	—	0:05	—
Relays	—	—	0:10	—
	3:40	14:26	10:50	95:00
Travel Time*	1:00	3:00	1:00	—
	4:40	17:26	11:50	95:00**

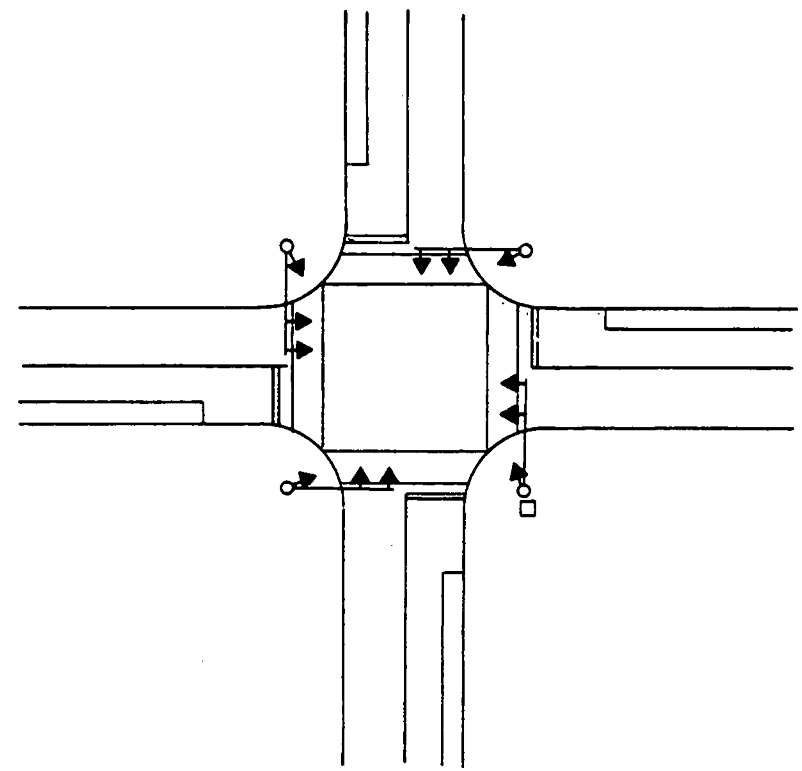
Therefore, per year: (4:40) x 4 + (17:26) x 2 + 11:50
= 65:22 hours

Record Keeping per year 3 hours

Total hours for Preventive Maintenance per year per intersection 68 hours

*1 hour per 6.5 hours of working time
**2-5 years maintenance time is not included in the yearly time estimates.

Case IV Intersection

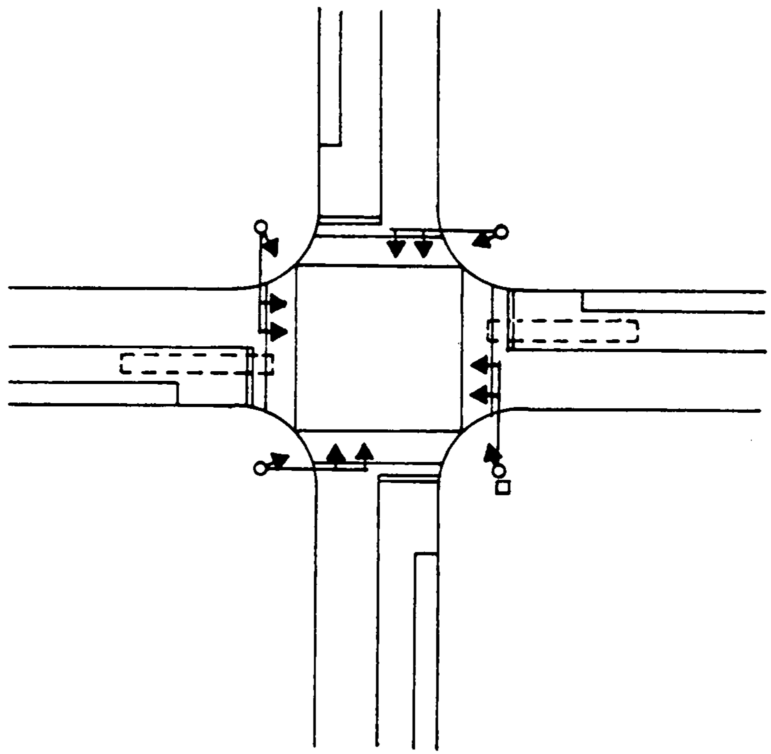


Intersection Estimates:

Same as Case I except the electromechanical controller is non-actuated and the two loop detectors (2 approaches) are deleted.

Total hours for Preventive Maintenance per year per intersection **31 hours**

Case V Intersection

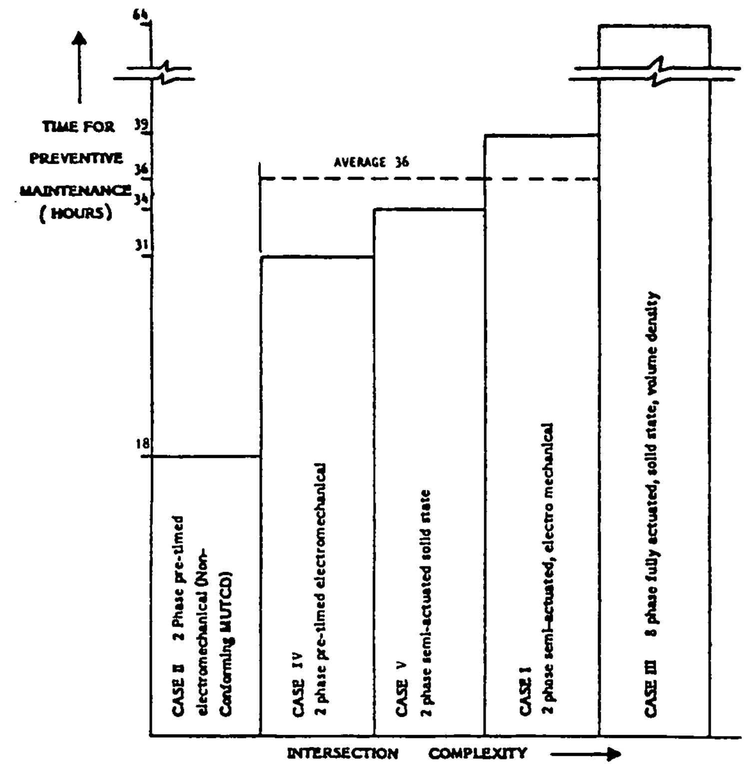


Intersection Estimates:

Same as Case I except that the electromechanical controller is replaced with solid state controller.

Total hours for Preventive Maintenance per year per intersection **34 hours**

ESTIMATED AVERAGE MANPOWER REQUIREMENTS PER INTERSECTION FOR PREVENTIVE MAINTENANCE



As the complexity of an intersection increases so does the time required for preventive maintenance. Only after taking a complete inventory of a municipality's traffic signal system, can one calculate the actual time needed per intersection for preventive maintenance. This average may vary greatly between municipalities. Therefore, we recommend using 36 hours per intersection for all calculations, which is the above average of the three most common types of intersection (i.e. I, IV and V).

ESTIMATED ANNUAL MANPOWER COSTS FOR OVERALL MAINTENANCE

The following tables are sample costs and time estimates for the purpose of showing the estimating procedure for annual manpower costs for overall maintenance. Each municipality should provide input for their individual time requirements and associated costs.

The annual productive work hours for maintenance personnel was estimated to be 1627 or 217 days per person. Using data obtained from Maintenance Questionnaire EK-29, the total time per intersection for preventive and response maintenance was estimated at 48 hours. Dividing the total time per intersection into the annual productive work hours resulted in the number of intersections that can be maintained by a single mechanic. Using the above information, a municipality can determine the most cost effective method of maintenance by comparing the municipal costs to contractor costs in their particular area.

Estimated Annual Work Hours Per Person

Work Hours Per Year: 52 Weeks x 40 Hours	2080	
Vacation: 3 weeks x 40 Hours	-120	
Sick Leave: 2 weeks x 40 Hours	-80	(16.5%)
Annual Training: 1 week x 40 Hours	-40	
Legal Holidays: 13 days x 8 Hours	-104	
	1736	
Coffee Break: .5 Hours per day x 217 days	-109	
Total Productive Time	**1627 Hours or 217 Days**	

Estimated Maintenance Time Distribution Requirements Per Intersection

Preventive Maintenance	36 hours** (75%*)
Response Maintenance	12 hours (25%*)
Total Time/Intersection	48 hours (100%)
Estimated yearly hours per mechanic:	1627
Therefore the number of intersections that can be maintained by one signal mechanic:	$\frac{1627}{48}$ = 34 intersections

Estimated Annual Cost For a Signal Mechanic

Average salary per signal mechanic	$16,000.*
+ 40% fringe benefits	$ 6,400.
(Assuming no building rental) Assuming initial equipment cost: $50,000. Prorated over 5 years	$10,000.
Yearly expense for maintaining 34 intersections	$32,400.

Evaluation of the break even line for maintenance by private contractor or municipality:
Annual maintenance budget: $32,400.

Assume contractor rate:
$30.00.
Then:
Hours of service with above budget (32,400) ÷ 30 = 1080 hrs.
75% of these will be spent on Preventive Maintenance = 810 hrs.
Each intersection requires 36 hrs. therefore the total number of intersections serviced = 22.5
say 22

Thus if the number of intersections is greater than 22 it may be to a municipality's advantage to maintain these signals.

* Data obtained from Maintenance Questionnaire EK-29. ** Data obtained from averaging case estimates.

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 I ☐ FOREMAN ☐ RAILROAD ☐ OTHER .... TIME:

9 CAUSE OF DAMAGE
Name
Address
Others ________ License No. ________

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

11

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

12 CHECK LOCATION

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

DT 511 (2M 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)

Heads, install or remove
Heads, replace
Heads, repair or adjust (2876)
Backplate, install or remove
Backplate, replace
Backplate, repair or adjust
Ped heads, install or remove
Ped heads, replace
Ped heads, repair or adjust (2876)
Push buttons, install or remove
Push buttons, replace
Push buttons, repair or adjust

Stiffeners, install or remove ______
Stiffeners, replace ______
Stiffeners, repair or adjust ______
Thru bolts, install or remove ______
Visor or louvre, install or remove ______
Visor or louvre, replace ______
Visor or louvre, repair or adjust ______
Overhead, repair or adjust ______
Standard, repair or adjust ______
Others, explain ______ Units

Units SIGNAL MAINTENANCE INSPECTION (2157)

Work by contractor
Mark out
Prepare conduit run diagram
Inspect, check, trouble shoot when no work is required
Meet engineer, contractor, etc.
Fill out Completion Notice, Update Form
Check intersection for Accounting
Others, explain

SIGNAL UNDERGROUND MAINTENANCE (2301) Units

Repair cable ______
Replace pull box lid ______
Replace pull box ______
Replace detector pad ______
Pull cable (each 10') ______
Other, explain ______

Units CONTROLLER FIELD MAINTENANCE (2356) Units

Install or remove:
Decoder
Synchronizer
Encoder
Sensor
Relay
Fan
Clock
Timer
Dial
Entire controller
Others, explain

Replace:
Decoder ______
Synchronizer ______
Encoder ______
Sensor ______
Relay ______
Fan ______
Clock ______
Timer ______
Dial ______
Entire controller ______
Others, explain ______

Repair, Adjust, Tone:
Decoder
Synchronizer
Encoder
Sensor
Relay
Fan
Timer
Dial
Others, explain

Connect interconnect ______
Connect telephone interconnect ______
Connect fire alarm interconnect ______
Disconnect interconnect ______
Change timing ______
Prepare timing charts ______
Put back charts-plans-card-etc. ______
Hook up loops ______
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 ______

PREVENTIVE MAINTENANCE PROCEDURES

PRETIMED SYSTEMS

Source: City of Atlanta Bureau of Traffic and Transportation

1. PRETIMED SECONDARY

   1.1 Lubrication

   - Lubricate dial needle bearing
   - Lubricate cam shaft bushings - both ends

   1.2 Contact Cleaning & Burnishing, etc.

   - Check signal contacts. Align and burnish
   - Check gear mesh and adjust as necessary

   1.3 Operational Check

   - At master, switch to each dial of operation
   - Check transfer relays for proper operation
   - Check motor for proper speed (does dial reset each cycle, etc.?)
   - Check operation of offset relays
   - Check each offset which is supposed to be in operation in system
   - Check operation of ratchet mechanism. Is operation positive and sharp?
   - Check to see if all timing keys firmly set in dial

2. PRETIMED MASTER

   2.1 Lubrication
   Same as secondary

   2.2 Contact Cleaning & Burnishing
   Same as secondary

   2.3 Operational Check

   - Check time of all clocks and reset as needed
   - Using clocks, transfer oper. to dial 2 and dial 3
   - Using clocks, transfer to offset 2 and offset 3 (only if these offsets used in this system)
   - Check transfer relays for proper operation
   - Check master offset relay for proper operation

METHODOLOGY FOR PREVENTIVE MAINTENANCE CREW

Source: City of Atlanta Bureau of Traffic and Transportation

1. Use PM procedures previously outlined and standard PM forms. Form should include list of all signals in system.

2. Begin with master.

   2.1 What is operational?

   - dials
   - offsets
   - clocks

   2.2 Inspect operation for D1, R1

   2.3 Switch to D2, R1, check operation

   2.4 Switch to D3, R1, etc., check operation and clocks

   2.5 Lubricate parts with PAO-30

   2.6 Check and adjust, if needed, gear train

   2.7 Check and adjust, if needed, contacts and relays

3. Leave on D1, R1 and Inspect Secondaries

   3.1 Go to each Secondary and inspect operation of secondaries

   3.2 Correct any faults found

   3.3 Switch master to D2, R1 and inspect operation of secondaries

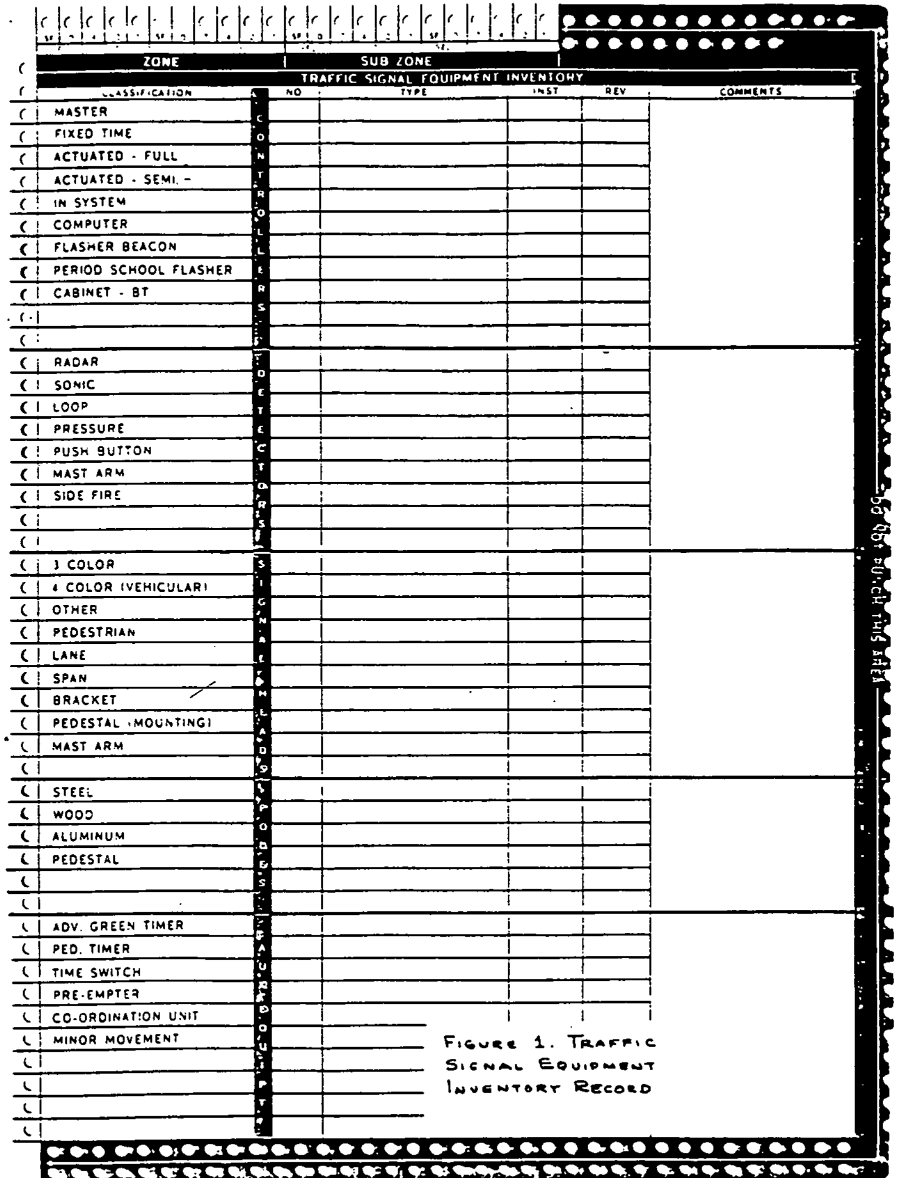
   3.4 Correct any faults found - especially dial transfer and offset relays

   3.5 Switch master to D3, R1 and inspect operation of secondaries

   3.6 Correct any faults found - especially dial transfer and offset relays

   3.7 Lubricate parts

   3.8 Check local flasher



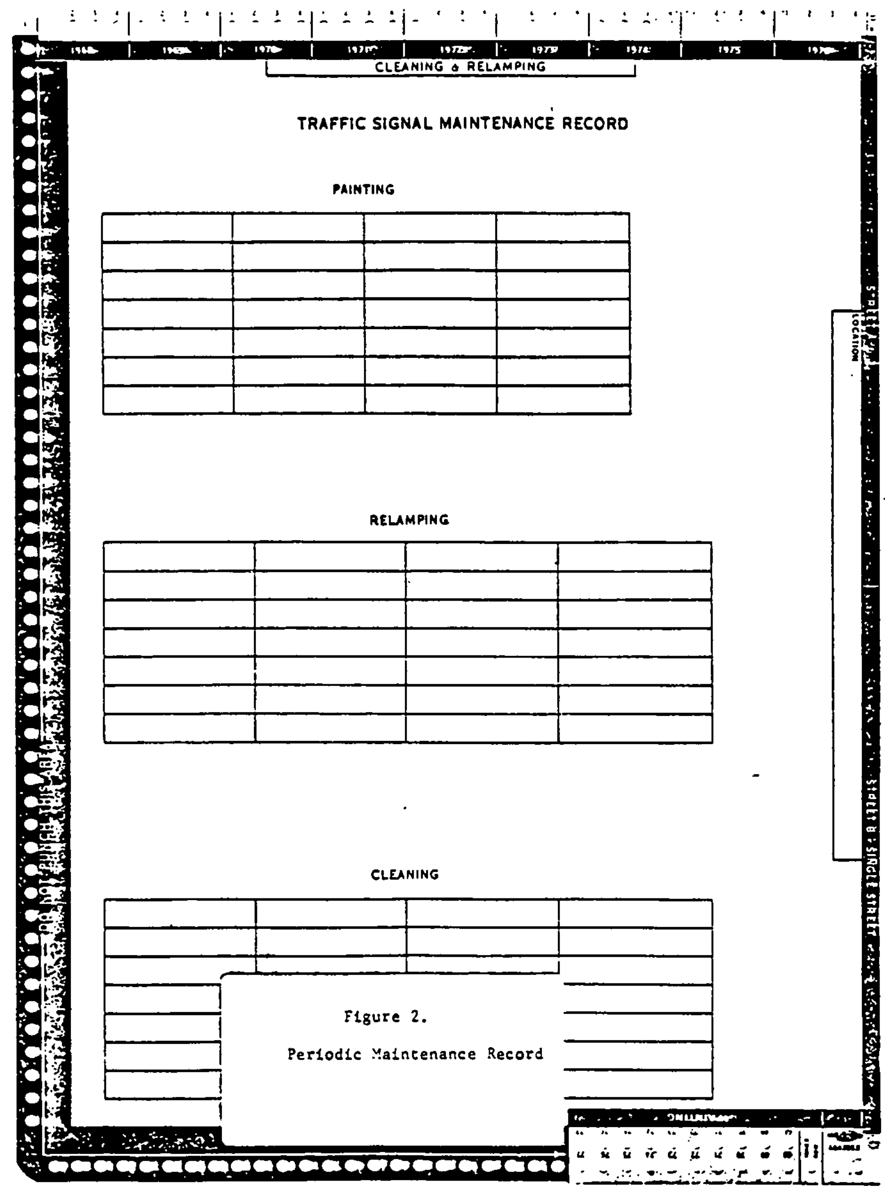
ZONE | SUB ZONE

TRAFFIC SIGNAL EQUIPMENT INVENTORY

CLASSIFICATION	NO	TYPE	INST	REV	COMMENTS
MASTER					
FIXED TIME					
ACTUATED - FULL					
ACTUATED - SEMI. -					
IN SYSTEM					
COMPUTER					
FLASHER BEACON					
PERIOD SCHOOL FLASHER					
CABINET - BT					
RADAR					
SONIC					
LOOP					
PRESSURE					
PUSH BUTTON					
MAST ARM					
SIDE FIRE					
3 COLOR					
4 COLOR (VEHICULAR)					
OTHER					
PEDESTRIAN					
LANE					
SPAN					
BRACKET					
PEDESTAL (MOUNTING)					
MAST ARM					
STEEL					
WOOD					
ALUMINUM					
PEDESTAL					
ADV. GREEN TIMER					
PED. TIMER					
TIME SWITCH					
PRE-EMPTER					
CO-ORDINATION UNIT					
MINOR MOVEMENT					

DO NOT PUNCH THIS AREA

Figure 1. Traffic Signal Equipment Inventory Record



CLEANING & RELAMPING

TRAFFIC SIGNAL MAINTENANCE RECORD

PAINTING

RELAMPING

CLEANING

DO NOT PUNCH THIS AREA

Figure 2.

Periodic Maintenance Record

City of Atlanta
Department of Environment and Streets
Bureau of Traffic Engineering

TRAFFIC SIGNAL PREVENTIVE MAINTENANCE RECORD

Location ______________________________

____

Type Controller: ☐ Actuated ☐ Pretimed ☐ Master ☐ Secondary

Model ____________

In System ☐ Isolated ☐

System No. ____________

Lubrication

- ☐ Dial
- ☐ Cam Shaft
- ☐ ____________
- ☐ ____________
- ☐ ____________

Cleaning/Burnishing

- ☐ Signal Contacts
- ☐ Step Switch - Cam Contacts
- ☐ Relays
- ☐ Motors
- ☐ ____________

Operational Check

- ☐ Signal Display
- ☐ Detectors
- ☐ Push Buttons
- ☐ Dial Gear Mesh
- ☐ Dial Transfer Relays
- ☐ Motor Speed
- ☐ Offset Relays
- ☐ Ratchet Mechanism
- ☐ Chattering Relays
- ☐ Timing Keys in Place
- ☐ Time Clocks - Set Time
- ☐ Time Clocks - Operation
- ☐ Signal Relay
- ☐ Auxiliary Devices
- ☐ Fuses
- ☐ Signal Contacts Tight
- ☐ Timing Dial Operation
- ☐ Flasher
- ☐ Signal Monitor

Form 46-52

City of Atlanta
Department of Environment and Streets
Bureau of Traffic Engineering

INSPECTION FOR OTHER PHYSICAL DEFECTS

Location ______________________________

____

- ☐ Signal Heads
- ☐ Messenger Wire
- ☐ Cable
- ☐ Pedestal
- ☐ Pole
- ☐ Detector
- ☐ Cabinet
- ☐ ____________
- ☐ ____________

Problems and Repairs

Problems: ______________________________

____

____

____

____

Repairs and Materials: ______________________________

____

____

____

All repairs made ☐

Signed ____________

Date ____________

Follow-up required ☐

If checked, list items below: ______________________________

____

____

Follow-up Complete ☐

Signed ____________

Date ____________

Form 46-53
(Rev. 3/75)

VIRGINIA BEACH

DAILY WORK ORDER LOG
SIGNAL CLEANING & RELAMPING
1979

ZONE	LOCATION	DATE OUT	DATE IN	CREW

ON SITE SIGNAL MAINTENANCE FORM

INTERSECTION:______________________________ NUMBER__________

BT NUMBER:____________________ TYPE CABINET:_____

TYPE MAINTENANCE PREFORMED (CHECK ONE):

( ) SCHEDULED PREVENTIVE

( ) SPECIAL, REQUESTED BY:____________________ DATE:________

SCHEDULED PREVENTIVE MAINTENANCE:

_____ THERMOSTAT
_____ FILTER
_____ ROTATE THUMBWHEEL SWITCHES
_____ DOOR SWITCHES
_____ SIGNAL HEIGHT
_____ MS CONNECTORS (TIGHTNESS)
_____ VACCUM CABINET
_____ LUBRICATE CABINET DOORS
_____ BT CONDITION
_____ TERMINAL CONNECTIONS

CABINET CONDITION (NOTE ANY DEFICIENCIES AND CORRECTIVE ACTION TAKEN):

EQUIPMENT:

CONTROLLER TYPE_______ SERIAL #________ REPLACEMENT SERIAL #______
AUXILIARY EQUIP_______ SERIAL #________ REPLACEMENT SERIAL #______

EQUIPMENT CONDITION (NOTE ANY DEFICIENCIES AND CORRECTIVE ACTION TAKEN):

SU-12 CONFLICT MONITOR (CHECK IF OKAY, OTHERWISE NOTE DEFICIENCIES BELOW)___

SU-12 TIME DELAY:______ SEC.

SPECIAL MAINTENANCE PREFORMED (DESCRIBE FULLY):____________

ON SITE SIGNAL MAINTENANCE FORM

INTERSECTION: OCEANA BLVD & DAM NECK NUMBER 44

BT NUMBER: 18494 TYPE CABINET: G

TYPE MAINTENANCE PREFORMED (CHECK ONE):

(✓) SCHEDULED PREVENTIVE

( ) SPECIAL, REQUESTED BY: ____________ DATE: ________

SCHEDULED PREVENTIVE MAINTENANCE:

- NA THERMOSTAT
- NA FILTER
- NA ROTATE THUMBWHEEL SWITCHES
- ✓ DOOR SWITCHES
- 14' 11" SIGNAL HEIGHT
- ✓ MS CONNECTORS (TIGHTNESS)
- ✓ VACCUM CABINET
- ✓ LUBRICATE CABINET DOORS
- GOOD BT CONDITION
- ✓ TERMINAL CONNECTIONS

CABINET CONDITION (NOTE ANY DEFICIENCIES AND CORRECTIVE ACTION TAKEN):

GOOD

EQUIPMENT:

CONTROLLER TYPE 1826 MFI SERIAL # 266183 REPLACEMENT SERIAL # ________

AUXILIARY EQUIP ________ SERIAL # ________ REPLACEMENT SERIAL # ________

4-SR-4
1-F-2
2-215
1-235
1-MR-10

EQUIPMENT CONDITION (NOTE ANY DEFICIENCIES AND CORRECTIVE ACTION TAKEN):

GOOD

SU-12 CONFLICT MONITOR (CHECK IF OKAY, OTHERWISE NOTE DEFICIENCIES BELOW) ___

- NA

SU-12 TIME DELAY: ______ SEC.

SPECIAL MAINTENANCE PREFORMED (DESCRIBE FULLY):

RE WIRED DETECTOR HARNESSES - IT WAS
A HUMONGOUS MESS

CLEANED ALL LENSES - CHECKED JOINTS FOR UPTURN
RE-BULBED ALL SIGNALS 22 BULBS -

APPENDIX B

FORMS FOR OTHER THAN PREVENTIVE MAINTENANCE

Many additional forms have been published by the International Municipal Signal Association (3).

The forms from Pennsylvania were prepared by Edwards and Kelcey for the Pennsylvania DOT (13).

The form from Iowa City was developed to record maintenance calls (15).

The forms from Atlanta are used in their corrective maintenance program. The last of the four is stored in the signal cabinet in a protective plastic envelope.

The three maintenance forms from Macon were provided by Gene O. Simonds, Electrical Department Director.

PENNSYLVANIA

MASTER INTERSECTION RECORD OF

________________________________ AND

INTERSECTION NUMBER______________

Reason For Intersection Inspection

	Date	Maintenance (Check Type Performed)		Design Modification (Include Brief Description)	Work Performed by (Signature)
		Preventive	Response		
1.					
2.					
3.					
4.					
5.					
6.					
7.					
8.					
9.					
10.					

MAINTAINING AGENCY

____

6.2 RESPONSE REPAIR LOG ON SHEET

DATE NO.

Called in By	Date	Time Received A.M. P.M.	Location	Trouble Record as Received	Actual Trouble as Found	Taken By	Person Assigned	Time Dispatched A.M. P.M.	Time Cleared A.M. P.M.

6.3 RESPONSE MAINTENANCE REPAIR RECORD SHEET

INSTRUCTIONS: PLEASE FILL IN THE BLANKS AND/OR CHECK THE APPROPRIATE ANSWER(S).

MUNCIPALITY: ____________________

LOCATION: ____________	LOCATION NUMBER: ______	DATE: ________
REPORTED BY: ________ AT: ____ AM / ____ PM	POLICE NOTIFIED: ☐ YES ☐ NO AT: ____ AM / ____ PM	OFFICERS NAME AND RANK: ________

REPORTED TROUBLE: ____________________

WEATHER CONDITIONS: ☐ CLEAR ☐ RAIN ☐ SNOW ☐ ICE ☐ FOG AMBIENT TEMPERATURE: ______ °F

GIVEN TO: ____________ AT: ____ AM / ____ PM TRUCK NUMBER: ______

CONDITION FOUND ON ARRIVAL: ____________________ TIME OF ARRIVAL ____ AM / ____ PM

WORK PERFORMED: ____________________

- ☐ 1. Lamp Out
- ☐ 2. Detector Sensor Failure
- ☐ 3. Detector Amplifier Failure
- ☐ 4. Load Switch Failure
- ☐ 5. Conflict Monitor Failure
- ☐ 6. Timing Incorrect
- ☐ 7. Signal Stuck
- ☐ 8. Signal Out
- ☐ 9. Lack of Progression
- ☐ 10. Interconnect Failure
- ☐ 11. Systems Masters Failure
- ☐ 12. Power Failure
- ☐ 13. Signal Damaged
- ☐ 14. Pole Knockdown
- ☐ 15. Controller Knockdown
- ☐ 16. Guy Wire Down
- ☐ 17. Span Wire Down
- ☐ 18. Other ____________

CONDITION ON DEPARTURE: ____________________ TIME OF DEPARTURE: ____ AM / ____ PM

☐ EMERGENCY REPAIR ☐ FINAL REPAIR

PARTS REPLACED OR REPAIRED: ____________________

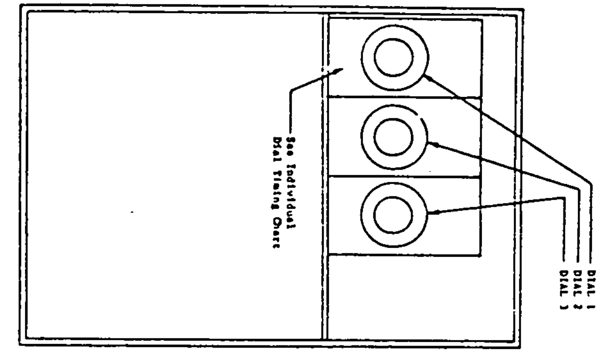
SIGNATURE OF SUPERVISOR: ____________ SIGNATURE OF REPAIR PERSON: ____________

TIMING CHART

Intersection of ____________

With ____________

Number ____________

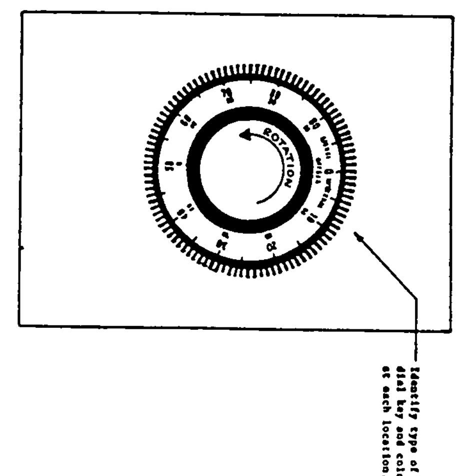


6.6 Controller Dial Chart

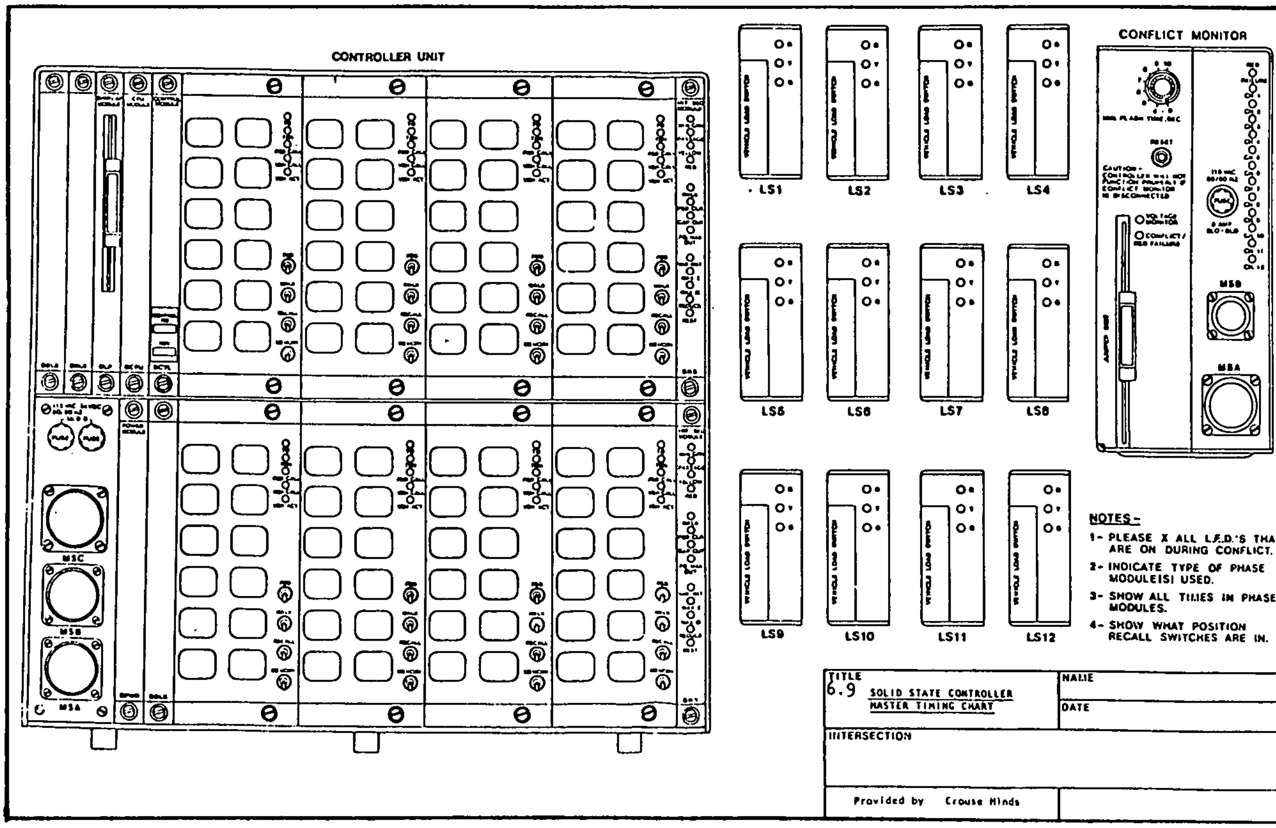
TIMING CHART

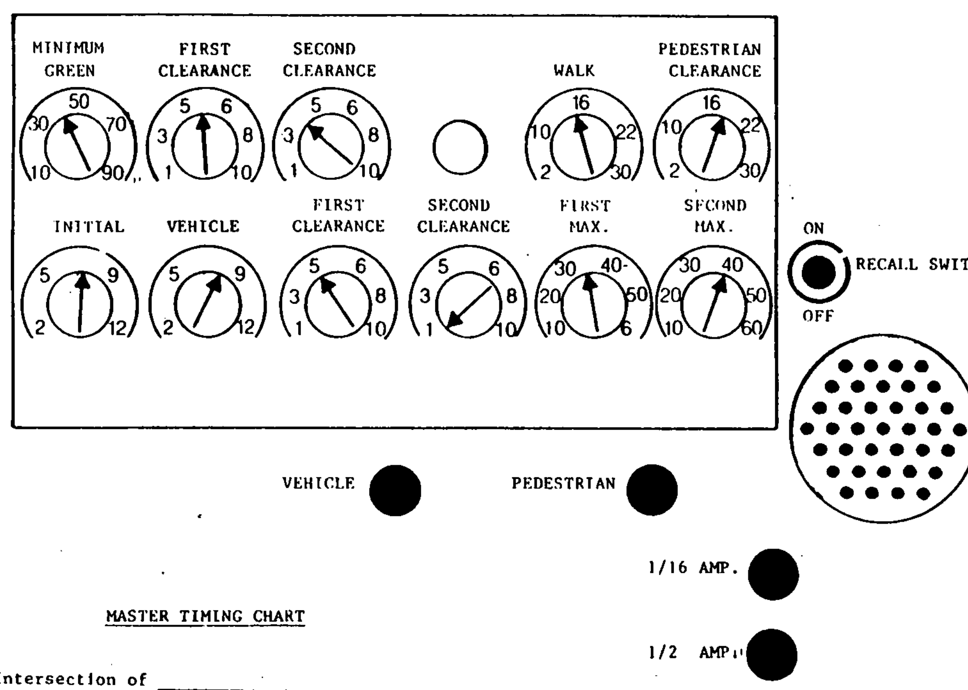
Dial ______

Cycle Gear ______ Second



6.7 Dial Timing Chart





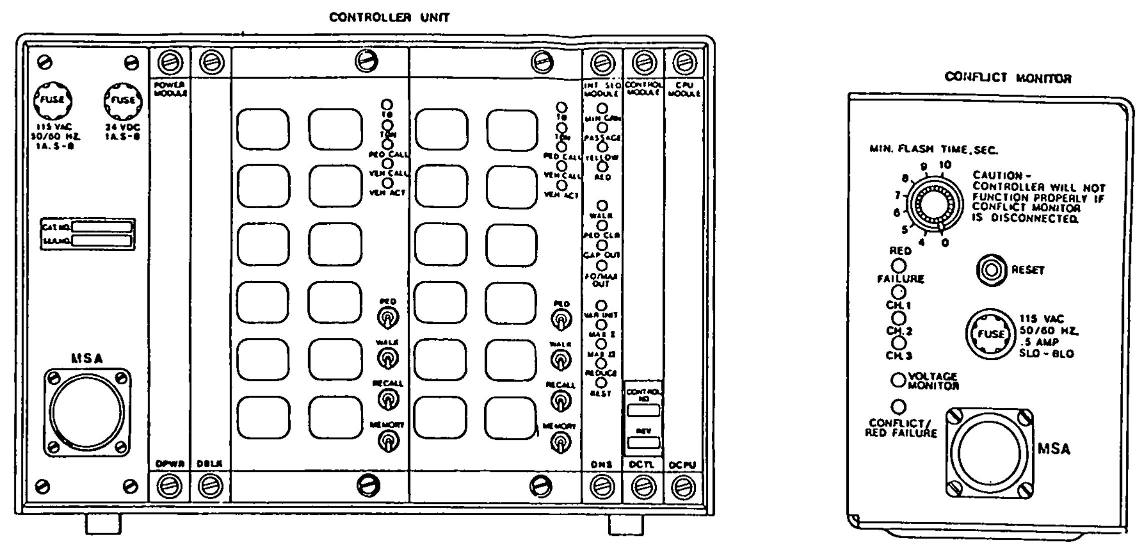
MASTER TIMING CHART

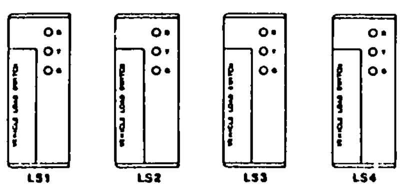
Intersection of ____________________

With ______________________________

Number ____________________

6.3 Analog Controller Master Timing Chart

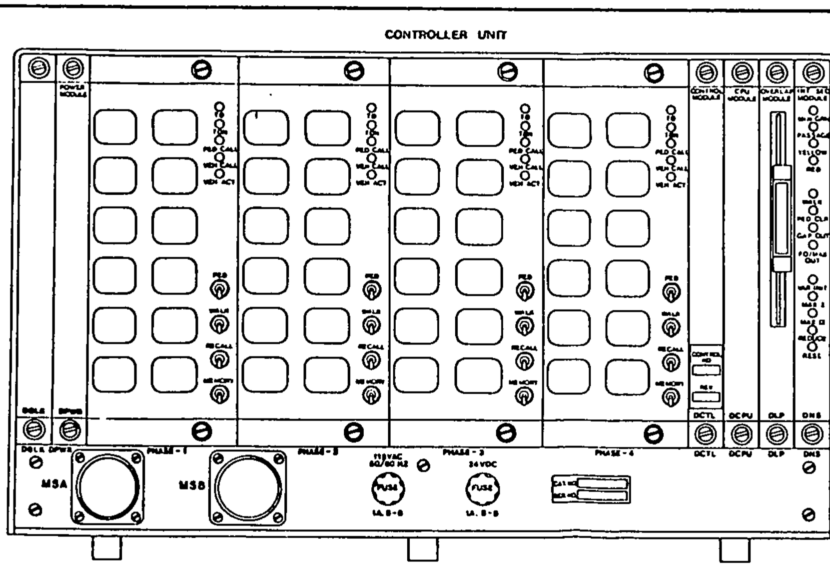


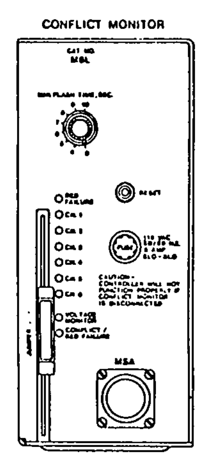


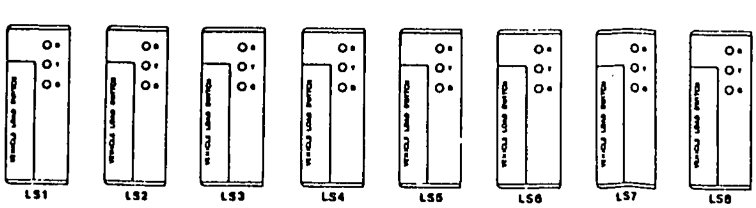
NOTES-

1- PLEASE X ALL L.E.D.'S THAT ARE ON DURING CONFLICT.
2- INDICATE TYPE OF PHASE MODULE(S) USED.
3- SHOW ALL TIMES IN PHASE MODULES.
4- SHOW WHAT POSITION RECALL SWITCHES ARE IN.

TITLE 6.9 SOLID STATE CONTROLLER MASTER TIMING CHART	NAME
	DATE
INTERSECTION	
Provided by Crouse Hinds	







NOTES-

1- PLEASE X ALL L.E.D.'S THAT ARE ON DURING CONFLICT.
2- INDICATE TYPE OF PHASE MODULE(S) USED.
3- SHOW ALL TIMES IN PHASE MODULES.
4- SHOW WHAT POSITION RECALL SWITCHES ARE IN.

TITLE 6.9 SOLID STATE CONTROLLER MASTER TIMING CHART	NAME
	DATE
INTERSECTION	
Provided by Crouse Hinds	

IOWA CITY

Order No.	Primary Street		At	Secondary Street	
Quadrant NW NE SW SE	Last X Street				NB SB EB WB
	Reported by:			Time	Date
Install	Replace	Remove	Reinstall	Repair	Check

CONTROLLER		ADDITIONAL INFO.
DETECTOR		
STREET LIGHT		
LAMP		
RED		
YELLOW		
GREEN		
WALK		
DON'T WALK		
LEFT TURN		
RIGHT TURN		
STRAIGHT		

Issued by:	Checked by:	Other action taken – detail on back of yellow copy and check here			
Assigned to:	Time AM PM	Date	By:	Time AM PM	Date

ATLANTA

CITY OF ATLANTA

Bureau of Traffic Engineering

Traffic Signal Swap-Out and Repair Record

LOCATION ______________________________

____

DATE: ______________ TYPE CONTROLLER ______________

SERIAL NO. ______________

AUX. UNIT TYPE ______________

FOREMAN/TECHNICIAN ______________________________

COMMENTS ______________________________

____

Form 4ü-54

DAILY REPORT

DAY OF WEEK ______________

FOREMAN ______________

WATCH

7AM 3PM [ ]

3PM 11PM [ ]

11PM 7AM [ ]

LOCATION	DATE AND TIME CALL RECEIVED	DATE AND TIME CALL HANDLED	NATURE OF TROUBLE (Check One)					
			Controller	Detector	Signal Head	Lamp T.S.	Street Light	Other
			☐	☐	☐	☐	☐	☐

46-57 (Rev. 3/78)

BUREAU OF TRAFFIC ENGINEERING
DISPATCHER LOG SHEET

DATE: ______________ TIME: From ________ to ________ DISPATCHER ______________

CODE FOR TYPE OF REPAIR

CO – Controller
DE – Detector
SH – Signal Head
LTS – Lamp, Traffic Signal
SL – Street Light
O – Other

LOCATION	TRANSFERRED FROM PREVIOUS SHIFT	TRAFFIC SIGNAL	STREET LIGHT	OTHER	REPORTED BY	TIME REPORTED	ASSIGNED TO TRUCK NUMBER	TIME ASSIGNED	TIME CLEARED	TRANSFERRED TO FOLLOWING SHIFT	TYPE REPAIR	COMMENTS

CITY OF ATLANTA
BUREAU OF TRAFFIC AND TRANSPORTATION
Street Lights and Traffic Signals Division

EQUIPMENT SWAP-OUT LIST

Location	Date	Equipment Swapped	Foreman or EET

Form 46-G-54 2/83

DEPARTMENT OF ENVIRONMENT & STREETS – BUREAU OF TRAFFIC & TRANSPORTATION

Traffic Signal Malfunction & Maintenance Log Sheet

LOCATION: ______________

DAY–DATE & TIME OF MAINTENANCE	FOREMAN	MALFUNCTION REPORTED	MALFUNCTION FOUND AND CORRECTIVE ACTION

Form 46-67 5/81

SERVICE CALLS - TRAFFIC SIGNAL DIVISION

DATE	LOCATION	DESCRIPTION OF CALL	SERVICE PERFORMED	REC'D	ARR'D	COMPL'D	INT
-29-82	Houston-Broadway-Pio Nono	Lamp Out	Replaced bulb	0800	1000	1005	Z.S. T.W.
9-29-82	Riverside-Riverview	No Lights	GA Power	0100 1014	0910	0915	Z.S. T.W.
9-29-82	Houston-Guy Paine	Hung up	No Problem	1014	1020	1020	Z.S. T.W.
9-29-82	Houston-Broadway-Pio Nono	Hung up	Retuned Broadway detector	1015	1025	1030	Z.S. T.W.
10-1-82	Eisenhower-Oglesby	Left turn not working	No Problem	1645	1700	1715	Z.S.
10-1-82	Houston-Guy Paine	Signal blinking out	Replaced load Relay	2200	2215	2230	Z.S.
10-4-82	Mercer-Log Cabin	Red Lamp out	Replaced lamp	0800	1040	1045	Z.S. T.W. M.L.
10-4-82	Vineville-Calloway	Lamp out Green	Replaced lamp	1450	1450	1455	Z.S. T.W.
10-4-82	Macon Tech-Eisenhower	Lamp out Red	Replaced lamp	1540	1545	1550	Z.S. T.W.
10-4-82	Eisenhower-Key	Inbound L.T. Turned	Corrected	1540	1555	1600	Z.S. T.W.
10-4-82	Coleman-College	Flashing	Reset Conflict Monitor	1310	1320	1325	Z.S. T.W.
10-5-82	Third-Forest	Not Flashing	Cam in a bind Corrected	1300	1550	1600	Z.S. M.S.
10-6-82	Broadway-Raines	Hung up	No Problem	0800	0825	0835	Z.S.
10-6-82	Pio Nono-Hightower	L.T. not working	No Problem	2000	2015	2025	J.H.
10-8-82	Houston-Second-Chambers	Bulb out	Replaced 1-69w bulb	0924	1320	1325	T.W. Z.S. M.L.

CITY OF MACON
TRAFFIC SIGNAL & SIGN DIVISION
SERVICE CALL REPORT

LOCATION: ______

DATE ______ TIME: ______ RECV'D ______ ARRIVED

REPORTED BY: ______ PHONE ☐ RADIO ☐ VERBAL ☐

DESCRIPTION OF CALL

NOT CYCLING		FLASHING		MISSING	
NO LIGHTS		DAMAGED		SIGN TYPE	
LAMP OUT		TURNED		OTHER	

Remarks: ______

(*) SIGN LEGEND: ______

SERVICE PERFORMED—MATERIAL USED

Service: ______

Material: ______

Serviced By: ______ Date: ______ Time: ______ Completed

Reviewed: ______ Recorded: ______ Date

I.D. No. ______ F.Y. No. ______

MACON, GEORGIA

The form below is printed on three-part NCR paper--white, yellow and pink--and the reverse side of each form is a bill of materials (with space for entering quantity and description of each item). The yellow copy is retained by the department that originates the Job Order. The other two go to the shop that is to perform the work. Upon completion the filled-out white copy is returned to the originating department.

JOB ORDER

TRAFFIC ENGINEERING DEPT.
CITY OF MACON, GA.

PRIORITY	T.S.	
(A) (B) (R)	(1) (2)	
		AUTHORIZED DATE

LOCATION:

INSTRUCTIONS:

ACTION:

00663

COMPLETED NAME / TITLE

APPENDIX C

PERSONNEL CLASSIFICATIONS

PERSONNEL CLASSIFICATIONS*

Personnel required for maintenance of traffic signal and control equipment (from here on referred to as the equipment), can be classified into three categories based on their responsibilities, knowledge and skills:

1. Signal Mechanic. He/She will be completely responsible for the operation and troubleshooting of signals and electromechanical equipment. He/She will be responsible for response maintenance of solid state equipment up to the device exchange level in the field. He/She will be capable of diagnosing a vehicle loop failure and initiating corrective action. He/She will be able to tune detector amplifiers in the field. He/She will set and check the timing specified on the time plan sheets. He/She will have the ability to follow wiring schematics. He/She will be responsible for checking all field connections made and turn-on of the controller. He/She will also be responsible for periodic preventive maintenance of all equipment e.g. cleaning of lens, replacement of lamps, visors, aligning the signal head, checking and spot painting poles and mast arm brackets, cleaning of electrical contacts, etc., to ensure reliable operation of the signalized intersections. He/She will maintain records of all work performed and of the equipment inventory.

   He/She will be equipped with a service vehicle, test lamp, multimeter, standard tool kit and any additional tools as required.

2. Supervising Signal Mechanic. In addition to the responsibilities described for a signal mechanic, he/she will also be responsible for scheduling and recording work performed by himself/herself and other signal mechanics in the group. He/She will prepare quantity and cost estimates for the annual budget.

3. Signal Technician. He/She will be responsible for maintenance of solid state equipment in the field. He/She will have the experience, knowledge and skills to efficiently identify a failed module or recurring failures at the intersection. He/She may use a diagnostics module (if available) to aid in identifying the failed module. He/She will have extensive experience and knowledge for the operation and troubleshooting of electromechanical equipment. He/She will have to perform tests on incoming equipment. He/She will not be a ladder man. He/She will be required to check and set controller timing as specified by the traffic engineer. He/She may have the additional responsibility of scheduling, supervising and recording work performed by the signal mechanics. He/She will be equipped with a multimeter, a portable scope, a standard tool kit and other test equipment as required.

4. Signal Specialist. He/She will have extensive training and troubleshooting skills in electronics and software. He/She will have a thorough knowledge of the theory of operations of the equipment. He/She will be responsible for the diagnostics and repair of all solid state equipment to the chip level. He/She may use a manufacturer's diagnostic module, if available, to aid him/her in identifying the problem. It will be his/her responsibility to repair all the modules in the shop. He/She will occasionally make field trips to aid the Signal Technician in returning the equipment to normal operation. He/She will design any jigs or test equipment that are needed in quickly diagnosing/repairing a problem.

   He/She will implement the maintenance and repair record-keeping system. He/She will receive/ship equipment to the manufacturer and check any short shipments from the manufacturer. He/She will be responsible for the equipment incoming test. He/She is also responsible for a design review of the intersection/systems equipment for any recurring problems as a preventive maintenance procedure, e.g. loading of switch packs. He/She

*Source: Edwards and Kelcey, Inc., Maintenance of Traffic Signal Systems, prepared in October, 1981 for the Pennsylvania D.O.T.(13).

has the ability to make design modifications to implement or omit special functions, e.g. adding an overlap movement.

If the Signal Specialist is unable to identify the problem in the equipment, he/she will request factory assistance.

He/She will be equipped with accurate multimeter, oscilloscope, and other sophisticated meters deemed necessary, tools for removal and insertion of Integrated Circuits (IC), standard tool kit with a few additional tools to work on the IC's and other test equipment as required.

Basic assumptions made:

1. Detailed wiring diagrams are available.
2. Equipment is fully labeled.
3. Timing plans are developed by traffic engineers.
4. Maintenance manuals are available.

Definitions:

1. Device. A device is any circuit or module or set of modules enclosed in a single chassis and connected to other components in the cabinet via harnesses or wired connectors, e.g. controller, conflict monitor, flasher.
2. Module. Packaged functional assembly of electronic components for use with other such assemblies.

PERSONNEL CLASSIFICATIONS*

TRAFFIC SIGNAL SPECIALIST TRAINEE

Minimum Qualifications

I. Must possess a high school diploma or equivalent;

and II. Shall possess a valid State Class 5 driver's license and obtain a State Class 3 driver's license within six months of employment;

and III. Meet the current "Acceptable Health Requirements for the Position of Laborer" set forth by the State D.O.T.

Duty Description

Under direct supervision participates in an on-the-job training program for the installation, maintenance, and repair of fixed time, electromechanical, solid state, and microprocessor traffic control equipment. This training may be supplemented by formal classroom study to develop basic knowledge of all types of traffic control equipment presently in operation.

Specific Duties:

1. Assists in the installation, maintenance, and repair of all types of traffic control equipment. Learns by instruction on the job, and by participation, the methods and procedures to be followed in installation of equipment, troubleshooting, defective equipment and inspection of contract installations.
2. Participates in classroom training provided by the Department in the maintenance, troubleshooting and repair of special equipment currently in use. Takes Department of Transportation courses in shop and work area safety, equipment operations, record keeping, elementary D.C. electronics, and introduction to traffic signal controller and detector operations.
3. Receives on-the-job training and assists in bench repair of electrical and electromechanical signal equipment together with the proper use of associated test equipment. Participates in the repair and maintenance of street lighting systems, sign lights, navigation lights, etc. Assists in

*Source: D.O.T. of a large state that prefers not to be named.

the protection of the public and workmen at work sites, and in employee safety practices. Participates in record keeping associated with the traffic signal program.

4. Learns by participation, the proper operation of equipment used in traffic signal installation work. This includes, but is not limited to, trenchers, welding equipment, compressors, concrete mixers and pavement cutting saws. Performs simple preventive maintenance procedures on traffic signal service vehicles such as greasing and checking - adding oil and hydraulic fluid.
5. Assists in the inspection of traffic control signals and receives training on how to determine if they are working properly and timed correctly.
6. Participates in the installation of conduits, poles, pull boxes, cabinet bases and other signal structures. Assists in the unloading, storing and inventorying of supplies and equipment. Replaces bulbs, lenses and reflectors of traffic signals.
7. Assists in performing emergency repairs to traffic signal control equipment on a 24-hour basis where failure to act immediately would create a hazardous condition to the traveling public.

ASSISTANT TRAFFIC SIGNAL SPECIALIST

Minimum Qualifications

I. Must possess a high school diploma or equivalent;

and II. Shall possess a valid State Class 3 driver's license,

and
either

III. Two years of experience in the installation, repair and maintenance of electronic and/or electrical equipment;

or IV. One year of satisfactory experience as a Traffic Signal Specialist Trainee.

Duty Description

Under direct supervision assists in the installation, maintenance and repair of fixed time, electromechanical, solid state and microprocessor traffic control equipment. Participates in an on-the-job training program which may be supplemented by formal classroom study to include the development of knowledge and experience in all types of traffic control equipment presently in operation.

Specific Duties:

1. Assists in the installation, maintenance and repair of all types of traffic control equipment. Learns by instruction on the job, and by participation, the most effective methods and procedures to be followed in troubleshooting and repair of traffic signals and signal systems.
2. Participates in classroom and on-the-job training provided by the Department in the maintenance, troubleshooting and repair of complex signal equipment. Takes Department of Transportation courses in installation procedures, electronics, controller troubleshooting and repair, bench repair - electro-mechanical controllers and signal system fundamentals.
3. Receives advanced on-the-job training and assists in inspection of traffic control signals to determine if they are working properly and timed correctly, and in the installation of poles, conduits, pull boxes, cabinet bases and other signal structures. Participates in the bench repairs of electrical and electromechanical signal equipment and receives training in the repair of more complex equipment. Repairs street lighting systems, sign lights, navigation lights, etc. Assists in record keeping associated with the traffic signal program.
4. Operates equipment used in traffic signal installation work, including but not limited to trenchers, welding equipment, compressors, concrete mixers, and pavement cutting saws. Performs simple preventive maintenance procedures on traffic signal service vehicles such as greasing and checking - adding oil and hydraulic fluid.
5. Participates in the unloading, storing and inventory of supplies and equipment. Drives car or light truck when necessary, and receives training in the operation of heavy trucks and other heavy equipment used in traffic signal installation and maintenance work.
6. Performs emergency repairs to traffic signal control equipment on a 24-hour

basis where failure to act immediately would create a hazardous condition to the traveling public. Initially responds alone to emergency traffic signal malfunction calls and performs repairs or calls for assistance if an analysis of the malfunction indicates that additional help is required.

7. Supervises one or more subordinates when performing routine signal maintenance tasks such as relamping, painting poles and signal heads or installing in-pavement loop detectors.

TRAFFIC SIGNAL SPECIALIST

Minimum Qualifications

I. Must possess a high school diploma or equivalent;

and II. Shall have a valid State Class 3 driver's license.

and either

III. A. Successful completion of at least 80 course hours in basic electrical theory and practice at a State accredited education institution such as a vocational school or community college. Successful completion of military classroom training for the above specified course hours in the required subject matter will satisfy this training requirement.

The training in basic electrical theory and practice must include but is not limited to such subject areas as:

1. The relationship of voltage, amperage, resistance and wattage in AC and DC circuits and
2. Electric generation, transformation and distribution, and
3. Electrical safety for maintenance personnel, and
4. Commercial AC wiring and distribution systems, and
5. Conformance with the National Electrical Code.

and

B. Two years of experience in the installation, repair and maintenance of electronic and/or electrical equipment,

or IV. Four years of experience in the installation, repair and maintenance of electronic and/or electrical equipment,

or V. Two years of satisfactory experience as an Assistant Traffic Signal Specialists.

Duty Description

Under the general supervision of the Supervising Traffic Signal Specialist, serves as a crew leader responsible for the installation, maintenance and repair of fixed time, electromechanical, solid state and microprocessor traffic control equipment.

Specific Duties:

1. Supervises a Traffic signal crew, assigns work programs consistent with priorities established by the Supervising Traffic Signal Specialist, and evaluates the work performance of the crew. Assures the work conforms to appropriate industrial electrical and safety codes and specifications and makes sure that work zones are properly protected both for the motoring public and the members of his crew.
2. Assists the Supervising Traffic Signal Specialist in developing work schedules, resolving problem areas, and may assume overall responsibility for the program in his absence.
3. Supervises a crew in performing inspections, maintenance and repair of traffic signals, street and lighting systems, sign lights and navigation lights.
4. Provides on-the-job training for subordinates through the demonstration of and instruction in the proper methods and procedures. Attends formal training courses which will prove beneficial to his own background and experience.
5. Performs repairs on complex traffic control equipment both in the field and bench repairs in the shop. Determines which components can be repaired or must be replaced.
6. Analyzes problems and directs or performs repairs to traffic signal control equipment on a 24-hour basis where failure to act immediately would create a

hazardous condition to the traveling public. Initially responds alone to emergency traffic signal malfunction calls and performs repairs or calls for assistance if analysis of problem reveals need.

7. Demonstrates and instructs crew members on the proper operation and maintenance of all types of equipment used in traffic signal installation and maintenance work. This includes but is not limited to trenchers, welding equipment, compressors, concrete mixers, pavement cutting saws, etc. Performs simple preventive maintenance procedures on traffic signal service vehicles such as greasing and checking, adding oil and hydraulic fluid.

8. Periodically reviews inventories, equipment, and tools to assure proper controls are being exercised. Reviews records and reports to assure compliance with program needs and requirements.

SUPERVISING TRAFFIC SIGNAL SPECIALIST

Minimum Qualifications

I. High school diploma or equivalent;

and II. Shall have a valid State Class 3 driver's license; and at least one of the following minimum qualifications;

and
either

III. A. Successful completion of at least 80 course hours in basic electrical theory and practice at a State accredited educational institution such as a vocational school or community college. Successful completion of military classroom training for the above required course hours in the required subject matter will satisfy this training requirement.

The training in basic electrical theory and practice must include but is not limited to such subject areas as:

1. The relationship of voltage, amperage, resistance and wattage in AC and DC circuits; and
2. Electric generation, transformation and distribution; and
3. Electrical safety for maintenance personnel; and
4. Commercial AC wiring and distribution systems; and
5. Conformance with the National Electrical code.

and

B. Successful completion of at least 90 course hours in electronics at a State acredited educational institution such as a vocational school or community college. Successful completion of military classroom training for the above specified course hours in the required subject matter will satisfy this training requirement.

The training in electronics must include but is not limited to the following:

1. The electronic application of resistors, capacitors, coils and transformers.
2. Operation and repair characteristics of common analog electronic circuits which incorporate transistors, tracs and similar linear circuit devices.
3. Theory and operation of solid state digital logic circuits.
4. The operation and use of power supplies, voltmeters, oscilloscopes and other measurement and diagnostic instruments as used in the installation, maintenance and repair of solid state electronic circuits of the type commonly used in modern traffic signal controller assemblies.

and

C. Three years of satisfactory experience in the installation, repair and maintenance of solid state analog, digital or microcomputer based traffic signal control equipment.

or IV. One year satisfactory experience as a Traffic Signal Specialist.

Duty Description

Under general supervision, directs a traffic signal crew in the installation, maintenance, and repair of all traffic signal equipment. Supervises the training program of subordinate Traffic Signal Specialists in troubleshooting and repair of traffic signal equipment. Plans, schedules and supervises traffic signal work done by State forces. Advises project engineers on contract signal installations. Acts as expert witness for the State in litigations involving traffic signal operation or maintenance.

Specific Duties:

1. Supervises the traffic signal crews in the installation, maintenance and repair of all traffic signal equipment, and supervises the timely installation, maintenance and repair of electronic, solid state and microprocessor master controllers, coordination units and intersectional controllers.
2. Plans, schedules and supervises traffic signal construction, reconstruction and modification projects by State forces by determining equipment and materials required; mobilizing and instructing crews how to perform work properly and safely; contacting utility companies for service and location of underground facilities; directing the inspection of work at various stages of completion and instructing the crew on technical problems; and updating schematic prints for master reference files.
3. Advises project engineers on traffic signal contract work by interpreting state specifications and procedures; assisting when technical problems occur; inspecting work at various phases of progress and recommending necessary corrective measures; and recommending final acceptance on contract completion.
4. Trains or supervises the training of subordinate traffic signal installation specialists in the troubleshooting and repair of traffic signal equipment by directing testing procedures for new equipment; instructing crews in operating characteristecs of new equipment; advising crews on interpretation of schematic drawings; and instructing crews in the use of testing equipment.
5. Analyzes problem and directs or performs complex repairs to traffic signal control equipment on a 24-hour basis where failure to act immediately would create a hazardous condition to the traveling public. Initially responds alone to emergency traffic signal malfunction calls and performs repairs or calls for assistance if analysis of problem reveals need.
6. Appears as expert witness for the State in litigation involving the operation or maintenance of traffic signals and advises local agencies on the proper maintenance of equipment installed with State-Federal funds.
7. Provides technical advice to the Traffic Control and Operations Engineer in design and preconstruction reviews.
8. Plans and implements the periodic inspection program of all regional traffic signals and schedules necessary maintenance or schedules reconstruction or recommends contract reconstruction, as appropriate. Establishes priorities and work schedules in accordance with needs and budget limitations.
9. Reviews, approves and submits requisitions for equipment, materials and tools as well as required records of crew activities and inventory controls.

PERSONNEL CLASSIFICATIONS*

TRAFFIC SIGNAL TECHNICIAN I

Nature of Work

This is entry-level and semi-skilled electrical/electronic work as applied to traffic signal systems.

Incumbent will be in a work/training program for one year learning the trades through assisting skilled technicians in the areas of installation, maintenance, and repair of electrical/electronic systems. After completion of training, he/she will be evaluated by either a written, oral or performance testing or a combination of either. Upon successfully qualifying, he/she may be elevated to the hext higher technician classification. Advice and assistance are a available from a superior, who shall judge performance based upon observation of results achieved, written evaluations and other criteria necessary.

Examples of Work

Assists, performs and learns the installation and maintenance of traffic controllers, school and street flasher systems and the related devices. Learns the proper use of appropriate equipment and tools of the trade; performs other related duties as assigned.

Desirable Knowledge, Abilities and Skills

Limited knowledge of electrical and electronic devices.

Knowledgeable of the use of hand tools in the trade.

Ability and willingness to work in adverse weather conditions.

Ability and willingness to do manual labor.

Skill in driving pickup trucks or larger trucks with manual transmission helpful.

Desirable Education and Experience

High school education supplemented by course work or vocational school involving electrical/electronic trades, or

*Source: The following personnel classifications have been used by the City of Macon, Georgia since 1979 and were provided by Mr. Gene O. Simonds, Electrical Department Director, in October, 1982.

Any combination of education and experience in the electrical/electronic trades acceptable to the appointing authority.

Necessary Special Requirements

Must be physically fit and pass a thorough medical examination by City Physician including back X-ray.

Must possess a valid State of Georgia driver's license.

TRAFFIC SIGNAL TECHNICIAN II

Nature of Work

This is a skilled position in the electro-mechanical/electronic field as applied to traffic signal systems.

Incumbent is in a work/training capacity. Applying prior training and experience, under direction and supervision of senior traffic signal technicians, specifically in the field of installation, maintenance and repair of the various types of traffic control devices and systems.

Abilities, character, and performance will be monitored by on-the-job assessment by Senior Technicians. Their reports to the Supervisor will be a major factor in the periodic review of the incumbent.

Examples of Work

Under direct supervision, assists and performs in the installation, maintenance and service of sophisticated traffic control systems and devices.

Learns the prescribed method of equipment operation, use and test procedures; prepares the necessary field reports and parts/equipment use records; performs other operational and installation related duties as assigned.

When qualified, may perform independently by direction of Senior Technicians, in maintenance and repair of less complex electro-mechanical/electrical traffic devices; performs other related duties as assigned.

Desirable Knowledge, Abilities and Skills

Knowledge of mechanical, electrical and electronic basic principles as applied to traffic signal equipment.

Knowledge of materials, tools, vehicles/equipment used in traffic signal installation and maintenance.

Knowledge of safety precautions required by electrical hazards and equipment operation.

Ability to apply prior training and experience to the traffic signal systems and techniques.

Ability to read and understand wiring diagrams, drawings, schematics and blueprints.

Ability to analyze, locate and correct troubles efficiently in mechanical and electrical devices such as used in traffic signal systems.

Ability to safely and effectively operate motor vehicles, bucket trucks and other powered machines used in the trade.

Ability and willingness to perform rigorous manual labor, day or night, in all types of weather conditions.

Skill in use and care of hand/powered tools and basic test equipment used in installation, test and repair of mechanical/electrical devices.

Desirable Education and Experience

High school graduate, supplemented by course work and/or vocational school training in electrical/electronic theory and practice with one or more years experience.

Or any combination of education and experience in the electrical/electronic field acceptable to the appointing authority.

Necessary Special Requirements

Must be physically fit and pass a thorough medical examination by the City Physician, including back X-ray.

Must possess a valid Georgia driver's license.

TRAFFIC SIGNAL TECHNICIAN III

Nature of Work

This is a highly skilled, position in the field of electro-mechanical and electronic system techniques as applied to Traffic Signal Systems. The incumbent is in a work, instructional and supervisory capacity. Applying knowledge, prior training and expertise, as directed by the supervisor. Leadership qualities, technical abilities, performance and character of the incumbent, shall be regularly monitored and periodically evaluated by the supervisor.

Examples of Work

As assigned, shall direct and perform the installation, maintenance and service of the Traffic Control Systems and devices; understands and follows the prescribed procedures and methods of system installation, operation and field maintenance; prepares necessary field and shop reports; coordinates with other governmental and utilities personnel; performs independently as assigned, in field maintenance of all Traffic Control Systems within the responsibility of the Division. Additional duties include: after normal working hours and weekend emergency service; shop maintenance/repair of electro-mechanical equipment; assists the Supervisor by (a) on-the-job training, (b) monitoring and assessing the performance of subordinate Technicians; observe and report the performance and care given vehicles and equipment used by this Division; responsible that all safety rules and guidelines of the City and Department are strictly adhered to under all circumstances; performs other related duties as assigned.

Desirable Knowledge, Abilities, and Skills

Knowledge of electro-mechanical and electronic theory, principles and techniques as applied to traffic signal equipment/systems.

Knowledge of basic construction and installation methods and Uniform Codes relating to traffic signal systems.

Knowledge of materials, tools, vehicles and equipment used in traffic signal installation and maintenance.

Knowledge of safety rules and precautions required by electrical hazards and equipment operation.

Ability to apply prior training and experience to traffic signal systems and devices.

Ability to read, comprehend and explain wiring diagrams, schematics, technical drawings and manufacturers' manuals.

Ability to analyze, locate and correct troubles efficiently in systems and devices used in traffic signal systems.

Ability to instruct and train others in troubleshooting techniques as relates to this trade.

Ability to efficiently and safely operate motor vehicles, bucket trucks and other powered machines used in this trade. And to instruct others in their proper use.

Ability to schedule, work with and direct peers and junior grade technicians.

Ability and willingness to perform rigorous manual labor, day or night, in all types of weather conditions.

Skill in use and care of hand/powered small tools, test equipment used in installations and maintenance, powered bench and shop tools used in this trade.

<u>Desirable Education and Experience</u>

High school graduate, supplemented by college and/or vocational or military school training in electrical/electronic theory and practice.

Three or more years of industrial or military experience in related applications of electrical/electronic devices and systems.

Or any combination of education and experience in a related field or electrical/electronic systems, acceptable to the appointing authority.

<u>Necessary Special Requirements</u>

Must be physically fit and pass a thorough medical examination by the City Physician, including back X-ray.

Must be available for 24-hour off-duty call when assigned.

Must possess an unrestricted currently valid State of Georgia driver's license.

TRAFFIC SIGNAL ELECTRONIC TECHNICIAN

<u>Nature of Work</u>

This is a highly skilled position in the field of commercial electronics. Work specifically relates to shop and field assemble, testing, diagnostic routines, repair of electronic/electro-mechanical devices and assemblies as applied to traffic control.

The incumbent shall perform independently in a scheduled work/instruction capacity, applying knowledge, prior training and experience as directed. Technical abilities, performance, self improvement and character of the incumbent, shall be regularly monitored and periodically reviewed by a superior.

<u>Examples of Work</u>

Performs troubleshooting, repair and testing of all malfunctioning traffic actuated devices and systems; performs assembly and acceptance testing of all new traffic control devices and systems; trains and assists other technicians in diagnoses and proper corrective methods and solutions of field service technical problems; prepares and maintains prescribed service records; maintains the necessary replacement parts stock levels; performs other related duties as assigned.

<u>Desirable Knowledge, Abilities, and Skills</u>

Thorough knowledge of advanced principles and theory of electrical/electronic techniques as applied to traffic control equipment.

Knowledge of equipment, materials, tools and vehicles of the trade.

Ability to comprehend and explain theory and operation of traffic signal equipment by reference to wiring diagrams, schematics, logic charts and manufacturer's manuals.

Ability to analyze, locate, correct malfunctions and train others in troubleshooting and repair techniques.

Ability to schedule work and training to meet field performance standards and installation deadlines.

Ability and willingness to perform rigorous manual labor, day or night, in all weather conditions.

Highly skilled in the use of test equipment, hand and powered tools used in this trade.

<u>Desirable Education and Experience</u>

High school graduate, supplemented by college and/or vocational or military school training in electronic theory and practice, and

Four or more years of industrial, commercial or millitary experience in related applications and techniques or electronic devices and systems, or

Any combination of education and experience in a related field of electronics, acceptable to the appointing authority.

Necessary Special Requirements

Must be physically fit and pass a thorough medical examination by the City Physician, including back X-ray.

Must possess a valid State of Georgia driver's license.

Must be willing to accept after regular hour emergency duty when assigned.

TRAFFIC SIGNAL FOREMAN

Nature of Work

This position requires high technical and supervisory skills in the installation and maintenance of Traffic Signal Systems.

Work includes responsibility for scheduling, directing and/or supervising subordinates to meet the planned objectives of the Supervisor; participation in after normal duty hour maintenance service; assisting the Supervisor in the selection, training and performance assessment of subordinate Traffic Signal Technicians. Work requires initiative, knowledge and ability to apply skills acquired through experience. Performance is assessed by accomplishment, through reports and general supervision by the Supervisor.

Examples of Work

Supervises technicians engaged in Traffic Signal installations and maintenance. Performs test routines on all types of Traffic Signal equipment. Interprets blueprints, schematics and drawings. Replaces defective devices, makes proper adjustments, prepares operational reports. Responsible for operation and serviceability of all vehicles, machines and field service equipment used by this function. Acts for the Supervisor, in his absence. Does related work as required.

Desirable Knowledge, Abilities

Thorough knowledge of the techniques that are applied in testing and repairing electronic and electrical units of traffic control.

Knowledge of installation methods and layouts of traffic control systems.

Knowledge of working hazards and safety precautions.

Skill in use of craft machines, tools and test equipment.

Ability to maintain effective working relationship with other employees.

Detailed knowledge and experience in all Traffic Control Systems in the City of Macon.

Desirable Education and Experience

High school graduate, including or supplemented by Courses in electrical/electronic theory and/or equivalent experience in these fields.

Five years experience in electronic and electro-mechanical Traffic Signal System installation and maintenance, and in the general care and use of related vehicles, machines and facilities used in this craft.

TRAFFIC DIVISION SUPERVISOR

Nature of Work

This is responsible, professional work in administering city traffic signals and signs and marking services.

Work involves responsibility for directing and coordinating all the activities assigned to the City Traffic Control system. Duties include supervision of technical, clerical and laboring staff concerned with special aspects of traffic control services. General assignments for non-routine work are received from a superior, who reviews accomplishments through conferences, and reports. Work requires the exercise of considerable independent judgment.

Examples of Work

Investigates all matters concerning traffic control systems and reports thereon; prepares and administers Traffic Control Division's operating and capital budgets; investigates complaints; coordinates traffic aspects of City projects; prepares and issues work assignments to subordinates; supervises the

Traffic Signs and Markings section; keeps records and makes reports; insures all signs, markings, and other traffic control systems are operational; maintains signal charts and traffic diagrams; interprets blueprints, schematics and other related data; insures working inventory is available at all times; performs other related duties as required.

Desirable Knowledge, Abilities, and Skills

Comprehensive knowledge of the principles and practices of traffic control systems and their applicability to a municiple setting.

Knowledge of regulations, ordinances and policies pertaining to traffic control systems and the Georgia uniform traffic code.

Knowledge of the use and safety of tools of the trade.

Ability to supervise subordinates.

Ability to plan and develop major projects.

Ability to maintain records and make reports.

Ability to establish and maintain effective public and employee relationships.

Desirable Education and Experience

College graduate or equivalent, supplemented by an electronics or related course, or

Substitute two years of experience in a related trade per year of college credit, or

Eight years experience in an electronic/electro-mechanical field, or

Any equivalent combination of educational experience acceptable by the appointing authority.

Necessary Special Requirements

Must be physically fit and pass a thorough medical examination by a City Physician, including back X-ray.

Must possess a valid Georgia driver's license.

APPENDIX D

MAINTENANCE EQUIPMENT AND SUGGESTED STOCKS OF REPLACEMENT PARTS

In Appendix D, the Equipment Inventory List was supplied by the City of Atlanta, Bureau of Traffic and Transportation. The Itemized List of Equipment Requirements and Estimated Price for Replacement was taken from Edwards and Kelcey, Inc. (13), prepared in October, 1981 for the Pennsylvania Department of Transportation.

EMERGENCY ELECTRICAL TECHNICIAN

EQUIPMENT INVENTORY LIST

Source: City of Atlanta, Bureau of Traffic and Transportation

The following equipment items shall be carried on each trouble truck.

UNIT	QUANTITY
CONTROLLERS	
505A	1
804D	1
1826D	1
ST-827RFK	1
"E.R.C."	1
DETECTORS	
RD-2	1
RDR-2	1
LOOPS	2
RD-2 SENSITIVITY POT	1
AUXILIARY EQUIPMENT	
G-2 ADV. GREEN TIMER	1
G-4 ADV. GREEN TIMER	1
TM-27 COORDINATION UNIT	1
3-DIAL 30149 COORDINATION UNIT	1
SU-2 SIGNAL MONITOR	1
SU-12 SIGNAL MONITOR	1
MOTORS, RELAYS AND FLASHERS	
EF-10 DIAL MOTOR	1
EF-23 DIAL MOTOR	1
ECONOLITE/G.E. DIAL MOTOR	1
EF-23 DIAL TRANSFER RELAYS	2
EF-10 DIAL TRANSFER RELAYS	2
ECONOLITE/G.E. TRANSFER RELAYS	2
EF-23 FLASH RELAY	1
SR-3 LOAD RELAYS	2
SCR-3 LOAD RELAYS	2
SCR-4 LOAD PACK (RELAY)	2
SCR-7 LOAD PACK (RELAY)	2
ECONOLITE/G.E. FLASHER	1
EF-23 FLASHER	1
TF-1 FLASHER	1
EMERGENCY FLASHER	1
BULBS	
67 WATT INCANDESCENT	2 CARTONS (MIN.)
116 WATT INCANDESCENT	6 (MIN.)
150 WATT INCANDESCENT	6 (MIN.)
150 WATT "3M" SEAL BEAM	1

ITEMIZED LIST OF EQUIPMENT REQUIREMENTS AND ESTIMATED PRICE FOR REPLACEMENT

General Notes

NOTE 1. The percent (%) quantities shown in the columns are the percentage of the total number of the item in the "Equipment" column, unless indicated otherwise.

NOTE 2. The quantities recommended shall be maintained for each non-interchangeable item in use.
Example: Lenses 2 or 5%: implies 2 or 5% of each non-interchangeable in use.

NOTE 3. The maximum of the two quantities listed shall be used.
Example: Signal Lenses - 2 or 5%. A municipality has 5 intersections. Each intersection has 4-3 section signal heads i.e. a total of 20 identical signal lenses of each red, green and yellow.

5% of 20 = 1

However, the minimum number of spare lenses recommended is 2 of each color and this shall govern.

NOTE 4. The quantities recommended are the minimum and shall be replenished immediately to maintain these levels.

NOTE 5. "Same" in Level II or Level III implies the quantities recommended for these levels are the same quantities recommended for Level I.

NOTE 6. "As required" is used for various minor items necessary for preventive maintenance that shall be maintained in inventory.

NOTE 7. "If required" is used for items with a very low expected rate of failure and therefore do not warrant inventory.

NOTE 8. The quantities followed by (A) are required for level A preventive maintenance only.

NOTE 9. Prices shown in the columns are for 1 unit unless otherwise noted (i.e. gallons, pounds, etc.) and do not included shipping and tax where applicable.

NOTE 10. Prices shown are average prices and will vary from one manufacturer to another manufacturer and between different models of the same manufacturer.

NOTE 11. Prices shown are not for special order or absolute equipment.

NOTE 12. All prices have been rounded up to the largest whole dollar.

NOTE 13. Volume purchases will reduce prices.

ITEMIZED LIST OF EQUIPMENT REQUIREMENTS

Equipment	Level I	Level II	Level III	1981 Average Price Per Unit
Bucket Truck	For all 3 levels of maintenance: 1 or 3% of signalized intersections. If more than one truck			$ 35,000
Platform Truck	is required the following purchase pattern is recommended:			20,000
Ladder Truck	1. Bucket truck 2. Platform truck 3. Ladder truck 4. Bucket truck 5. Ladder truck			15,000
Multimeter	1 per person	same	same	100
Oscilloscope	1 per signal specialist	--	--	1,200
Controller Test Fixture (Bench Test)	1 or 2% of signalized intersections	same	same	2,000
Suitcase Tester	1 per signal specialist	--	--	2,000
Detector Sensor Test Equipment	1 per signal mechanic	same	same	600
Detector Test Fixture	1 per signal technician	same		500
Frequency Generator	1 per signal specialist	--	--	500
Frequency Counter	1 per signal specialist	--	--	800
Variac	1 per controller test fixture	same	same	100
Spring Tension Gauge	1 per signal mechanic	same	same	20
Small Tools	1 set per person	same	same	1,000
Vacuum Cleaner	1 per signal mechanic	same	same	100
Hardware Miscellaneous (such as electrical tape, wire, level, test lamp)	as required	same	same	100
Paint Miscellaneous (such as wire brushes, paint brushes)	1 set per signal mechanic	same	same	25

MECHANICAL

CABINET

Cabinet (shell)	1 or 2%	same		$400-1,000
Primer	1 gal. or 2 gal. per 5 cabinets (A)	same	same	20-/gal.
Paint	1 gal. or 2 gal. per 5 cabinets (A)	same	same	20/gal.
Oil	1 pint or 1 gal. per (A) 100 cabinets	same	same	5/gal.
Filter	1 or 1% *	same	same	1
Gasket	10' or 1%	same	same	1/ft.
Anchor Bolt	4 or 8% (A)	same		10 each
Duct Sealant	5 lb. or 5 lb. per 20 controllers	same	same	5/5 lbs.
Grounding Clamp	1 or 1%	same	same	1
Fan	2 or 5%	same	same	25
Heater	2 or 5%	same	same	10
Thermostat	2 or 5%	same	same	3
Lock and Keys	2 or 5% (A)	same	same	8
Miscellaneous Hardware (Brass and Stainless Steel)	as required	same	same	100

Equipment	Level I	Level II	Level III	1981 Average Price Per Unit
SIGNAL HEAD (PEDESTRIAN AND VEHICLE)				
Lamp	2 or 5% *	same	same	3
Lens	2 or 5%	same	same	$ 9-8" $ 22-12"
Visor	2 or 5%	same	same	$ 7-8" 12-12"
Reflector	2 or 5%	same	same	7-8" 12-12"
Lamp Socket	2 or 5%	same	same	3
Signal	2 or 5%	same	same	180-8" 250-12"
Signal Mounting Hardware	2 or 5%	same	same	75
Regulatory Sign	2 or 5%	same	same	50
Signal Cable	500 ft. of 5 conductor, AWG12	same	same	.25
Primer	l gal. or l gal. per (A) 5 signal heads	same	same	20/gal.
Paint	l gal. or l gal. per (A) 5 signal heads	same	same	20/gal.
MAST ARMS, POLES AND SPAN WIRE POLES				
Primer	l gal. or 5 gal. per pole (A)	same	same	20/gal.
Paint	l gal. or 5 gal. per pole (A)	same	same	20/gal.
Mast Arm	1 or 5%	same		750
Pole Shaft or Pedestal	1 or 5%	same		750
Anchor Bolt	4 or 8% (A)	same		25/each
Handhole Cover	1 or 2% (A)	same	same	10
Grout	100 lb. or 100 lb. bag per 100 foundations	same		10/100 lb.
Miscellaneous Hardware	as required	same	same	25
SPAN WIRE				
Messenger Cable Tensioner (come along)	1 per signal mechanic	same	same	100
Cable Clamp	2 or 5%	same	same	5
Anchor Bolt	4 or 8% (A)	same		$ 25/each
Span Wire	1000 ft. or 1000 ft. per 100 spans	same		2
Tether Wire	1000 ft. or 1000 ft. per 100 spans	same		1
Miscellaneous Hardware	as required	same	same	25
PUSH BUTTONS				
Push Button Assembly	2 or 5%	same	same	35
Lamp and Lens	2 or 5%	same	same	5
Sign	1 or 2%	same	same	50
Push Button Post	2 or 5%	same		$ 100-400
Miscellaneous Hardware	as required	same	same	25

Equipment	Level I	Level II	Level III	1981 Average Price Per Unit
DETECTOR SENSORS				
Re-enterable Splice Kit	1 or 1% (A)	same		46
Fluid for Re-enterable Splice Kit	2 pouches (21 oz ea.) or 5% of splices (A)	same		14/21 oz.
Sealant	1 gal. or 1 gal. per 25 ft. of sawcut	same	same	45/gal.
Sensor	2 or 5%	same	same	200
Pressure Pad	4 or 5%	same	same	400
Loop Wire	500 ft.	same	same	.16/ft.
Homerun Cable	1,000 ft.	same	same	1.00/ft.
UNDERGROUND				
JUNCTION BOXES AND HANDHOLES				
Spare Handhole Cover	1 or 2% (A)	same	same	$ 10
Junction Box Cover	1 or 1%	same	same	75
Miscellaneous Hardware	as required	same	same	5
ELECTRICAL				
Radio Interference Filters	1 or 2%	same	same	25
ELECTROMECHANICAL CONTROLLER				
Dust Cover	1 or 2%			15
Controller	1 or 2%	same	same	
DIAL ASSEMBLY				
Dial Unit	2 or 5%	same	same	180
Cycle Gear	2 or 5%	same	same	3
Key	2 or 5%	same	same	1
Motor	2 or 5%	same	same	50
Contacts	5 or 10%	same	same	3
Synchronizing Relay	2 or 5%	same	same	8
Amphenol Socket	1 or 2%	same	same	1
Miscellaneous Hardware	as required	same	same	25
CAM ASSEMBLY				
Cam	5 or 5%	same	same	$ 1
Advancing Mechanism	2 or 5%	same	same	70
Rachet and Pawl	2 or 5%	same	same	15
Contacts and Spring	5 or 10%	same	same	6
Shaft Bearing	if required	same	same	1

Equipment	Level I	Level II	Level III	1981 Average Price Per Unit
Oil	1 pint or 1 gal. per 100 controllers	same	same	5/gal.
Relay (Crouse-Hinds type)	10 or 20%	same	same	54
RELAYS				
Dial Transfer Relay	2 or 5%	same	same	110
Flash Relay	2 or 5%	same	same	70
Contacts	5 or 10%	same	same	5
Relay Connector	4 or 8%	same	same	1
FLASHERS				
Flasher Unit	1 or 3%	2 or 5%	2 or 5%	90
Contacts and Motor for Mechanical Type Flasher	5 or 10%	same	same	20
Flasher Connector	4 or 8%	same	same	1
Components	as required	--	--	25
SWITCHES				
Switch	1 or 1%	same	same	$ 3
Time Switch	2 or 5%	same	same	80
CONFLICT MONITOR				5 Channels $ 500
Conflict Monitor	1 or 3%	2 or 5%	2 or 5%	12 Channels $ 800
Components as Listed by Manufacturer	as required	--	--	$ 25
DETECTOR AMPLIFIER				
Detector Amplifier	2 or 10%	2 or 20%	2 or 20%	180/Channel
Power Supply for Amplifier	2 or 5%	2 or 10%		176
Components	as required	--	--	25
ANALOG CONTROLLERS				
Potentiometers	2 or 5%	2 or 5%	2 or 5%	3
Indicators	2 or 5%	2 or 5%	2 or 5%	1
Load Relays	2 or 10%	2 or 10%	2 or 10%	120
Miscellaneous Components	as required	--	--	25
Controller	1 or 2%	1 or 5%	1 or 10%	2,000
SOLID STATE AND MICROPROCESSOR BASED CONTROLLERS				
Load Switch	3 or 5%	same	same	100
Power Supply for Load Switches	2 or 2%	same		120
Load Switch Components	as required	--	--	$ 25
Solid State Replacement Relay for Load Switcher	3 or 30% of load switches	same	--	35

Equipment	Level I	Level II	Level III	1981 Average Price Per Unit
Controller	1 or 5%	same	same	See page 2-48
Module and Board	3 or 5%	same	--	See page 2-48
Power Supply for Controller	2 or 5%	same	--	See page 2-48
Other Components as Recommended by Manufacturer	as required	--	--	200
AUXILIARY LOGIC				
Backup Components per Logic Card (preemptor)	as required	--	--	100
INTERCONNECT EQUIPMENT				
Backup Master	--	--	--	--
Interface Unit	1 or 5%	2 or 10%	2 or 10%	1,000
Dial Unit (synchrolizer)	3 or 5%	1 or 5%	1 or 5%	250
Coordination Unit	1 or 5%	1 or 5%	1 or 10%	370
Miscellaneous Components	as required	--	--	50

* NOTE: 100% of these items will be required annually for group replacement.

ESTIMATED 1981 PRICE LIST FOR REPLACEMENT OF A SOLID STATE CONTROLLER TIMER WITH EXPANSIBLE FRAME

Number of Phases	Controller Chassis*	Phase Module	Total Cost
2	$3,100	$ 400	$3,500
3	3,100	600	3,700
4	3,100	800	3,900
5	3,100	1,000	4,100
6	3,100	1,200	4,300
7	3,100	1,400	4,500
8	3,100	1,600	4,700

*Includes mainframe, power supply, overlap modules, miscellaneous timers, etc.

APPENDIX E

MUNICIPALITY MAINTENANCE CAPABILITY CHECKLIST AND EVALUATION

The following questionnaires, diagrams, and evaluation forms comprising Appendix E were obtained from Edwards and Kelcey, Inc., Maintenance of Traffic Signal Systems (13). The report was prepared in 1981 for the Pennsylvania Department of Transportation.

PENNSYLVANIA DEPARTMENT OF TRANSPORTATION

MUNICIPALITY MAINTENANCE CAPABILITY

CHECKLIST FOR TRAFFIC SIGNALS

Instructions: Please fill in the blanks or check the appropriate answer(s).

NAME OF MUNICIPALITY:

____

COUNTY:

____

NAME OF PERSON FILLING OUT THE FORM:

________ ______________ TELEPHONE: ______________

GENERAL

1. TOTAL NUMBER OF SIGNALIZED INTERSECTIONS:__________
   - NUMBER OF ELECTROMECHANICAL CONTROLLERS:__________
   - NUMBER OF SOLID STATE CONTROLLERS:__________
   - NUMBER OF OTHER CONTROLLERS:__________
2. WHAT IS YOUR ANNUAL MAINTENANCE BUDGET INCLUDING SALARIES, AND EQUIPMENT? (EXCLUDE THE COST FOR NEW EQUIPMENT OR UTILITY COSTS) $__________
3. COMPLETE THE ATTACHED **BACKUP INVENTORY SHEET**
4. WHICH OF THE FOLLOWING MAINTENANCE RECORDS ARE KEPT.

   a. WIRING DETAILS YES NO

   b. TIME SETTING DETAILS YES NO

   c. DETECTOR TUNING DETAILS YES NO

   d. CHANGES MADE AT THE INTERSECTION YES NO

   e. PREVENTIVE MAINTENANCE PERFORMED YES NO

   f. RESPONSE MAINTENANCE PERFORMED YES NO

   g. THE TIME A FAILURE COMPLAINT IS REGISTERED. YES NO

   h. THE TIME THE INTERSECTION IS REACHED BY A MAINTENANCE CREW. YES NO

   i. THE TIME TAKEN TO RETURN OPERATION TO NORMAL. YES NO

5. DO YOU HIRE A CONTRACTOR FOR ELECTRO-MECHANICAL CONTROLLER MAINTENANCE? YES NO
6. DO YOU HIRE A CONTRACTOR FOR SOLID-STATE CONTROLS REPAIR? YES NO

MAINTENANCE BY MUNICIPALITY

IF ANSWER TO QUESTION 5 OR 6 IS NO, THEN FILL OUT THE FOLLOWING INFORMATION.

7. UPON FAILURE OF SOLID STATE CONTROL DOES YOUR CREW DETERMINE THE FAILED DEVICE(S) IN THE CONTROLS CABINET ONLY BY REPLACING EACH DETACHABLE CONTROL DEVICE UNTIL THE FAILED DEVICE(S) IS IDENTIFIED AND REPLACED? YES NO

   (Explanation: If your crew is capable of identifying and replacing, in the field, the failed component or module, then answer "NO" to this question.)

8. IS MAJORITY OF FAILED SOLID STATE EQUIPMENT REPAIRED IN YOUR SHOP? YES NO
9. COMPLETE THE ATTACHED **MANPOWER SUMMARY SHEET**
10. INDICATE THE QUANTITY OF EACH TYPE OF EQUIPMENT YOU HAVE:

	Type-	Quantity
Field	Bucket Truck	______
	Ladder Truck	______
	Platform Truck	______
	Dump Truck	______
	Automobile	______
	Panel Truck	______
	Other	______

10. Cont'd.

Shop		
	Multimeter	______
	Oscilloscope	______
	Controller Test Fixture	______
	Detector Test Fixture	______
	Frequency Generator	______
	Frequency Counter	______
	Variac	______
	Transister Checker	______
	Other	______

11. ARE YOUR MAINTENANCE VEHICLES EQUIPPED WITH: TWO-WAY RADIO COMMUNICATIONS? YES NO
TONE/VOICE ELECTRONIC PAGER? YES NO

12. DOES THE MAINTENANCE GROUP HAVE RESPONSIBILITIES OTHER THAN TRAFFIC CONTROL EQUIPMENT? YES NO

IF YES, WHAT ARE THEY? ______________________
WHAT PERCENT OF TIME? ______________________

CONTRACTOR MAINTENANCE

If answer to Question 5 or 6 is YES, then fill out the following information:

13. UPON FAILURE OF SOLID STATE CONTROL DOES THE CONTRACTOR'S CREW DETERMINE THE FAILED DEVICE(S) IN THE CONTROLS CABINET ONLY BY REPLACING EACH DETACHABLE CONTROL DEVICE UNTIL THE FAILED DEVICE(S) IS IDENTIFIED AND REPLACED? YES NO

(Explanation: If the contractor's crew is capable of identifying and replacing, in the field, the failed component or module, then answer "NO" to this question.)

14. **If answer to question 13 is NO: then answer the following question:**
DOES THE CONTRACTOR REPAIR MAJORITY OF THE FAILED EQUIPMENT IN HIS SHOP? YES NO

15. DOES THE CONTRACTOR CHARGE BY THE HOUR FOR EMERGENCY REPAIR? YES NO

IF YES, DOES THE RATE INCLUDE
- o MATERIAL? YES NO
- o EQUIPMENT? YES NO
- o TRAVEL? YES NO

WHAT IS THE HOURLY RATE? $ /HOUR

IF A CONTROLLER FAILS, IS THE OPERATION OF THE INTERSECTION RETURNED TO NORMAL WITHIN 24 HOURS? YES NO
WHAT IS THE AVERAGE REPAIR TIME? ______(HOURS/DAYS)

16. DOES THE CONTRACTOR RETURN THE FAILED EQUIPMENT TO YOU FOR REPAIR? YES NO

RESPONSE MAINTENANCE

17. DOES REPONSE TIME TO THE INTERSECTION TO VERIFY AND IDENTIFY THE REPORTED PROBLEM EXCEED 1 HOUR? YES NO

18. IF A CONTROLLER FAILS IN THE FIELD, CAN YOUR CREW OR CONTRACTOR RETURN THE OPERATION OF THE INTERSECTION TO NORMAL (PERMIT) WITHIN 24 HOURS? YES NO

19. If answer to question 18 is NO, then answer the following question:

IF NORMAL OPERATION IS NOT POSSIBLE, CAN YOUR CREW OR CONTRACTOR USE ALTERNATE MEANS OR MODE TO TEMPORARILY RESTORE THE SYSTEM TO SAFE OPERATION WITHIN 24 HOURS UNTIL NORMAL REPAIR CAN BE COMPLETED? YES NO

20. WAS FINAL REPAIR THEN COMPLETED WITHIN 30 DAYS? YES NO

21. DO YOU HIRE A CONTRACTOR FOR YOUR RESPONSE MAINTENANCE PROGRAM? YES NO

IF YES:

DOES THE CONTRACTOR CHARGE BY THE HOUR FOR RESPONSE MAINTENANCE? YES NO

IF YES:

DOES THE RATE INCLUDE:

- o MATERIAL? YES NO
- o EQUIPMENT? YES NO
- o TRAVEL? YES NO

WHAT IS THE HOURLY RATE? $ /HOUR

PREVENTIVE MAINTENANCE

22.	DO YOU HAVE A FUNCTIONAL PREVENTIVE MAINTENANCE PROGRAM (OTHER THAN RELAMPING)?	YES	NO
23.	DO YOU HIRE A CONTRACTOR FOR THE PREVENTIVE MAINTENANCE PROGRAM?	YES	NO
	IF YES:		
	DOES THE CONTRACTOR CHARGE BY THE HOUR FOR PREVENTIVE MAINTENANCE?	YES	NO
	IF YES, DOES THE RATE INCLUDE:		
	o MATERIAL?	YES	NO
	o EQUIPMENT?	YES	NO
	o TRAVEL?	YES	NO
	WHAT IS THE HOURLY RATE?	$	/HOUR

24. IF THE ANSWER TO 22 OR 23 IS YES, COMPLETE THE ATTACHED PREVENTATIVE MAINTENANCE QUESTIONNAIRE.

MANPOWER SUMMARY SHEET

	JOB CLASSIFICATION OR TITLE	NUMBER OF PERSONS	DESCRIPTION OF DUTIES	EDUCATION REQUIREMENTS	ANNUAL SALARY (NEAREST $1,000)
1.					
2.					
3.					
4.					
5.					
6.					
7.					
8.					
9.					
10.					

PENNSYLVANIA DEPARTMENT OF TRANSPORTATION

MUNICIPALITY MAINTENANCE CAPABILITY EVALUATION

NAME OF MUNICIPALITY:

____

Instructions:

1. (Q2) Implies Question 2 from "Municipality Maintenance Capability Checklist"

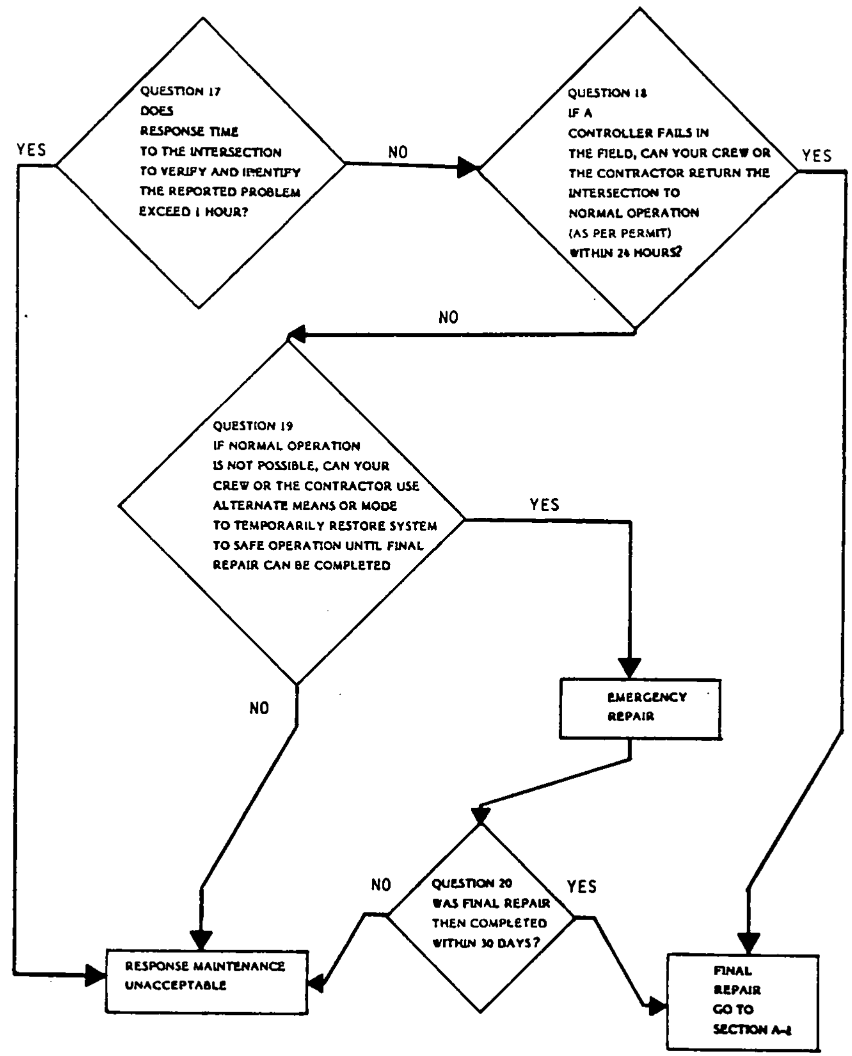
2. Transfer applicable answers from "Checklist" to "Evaluation"

NOT FOR GENERAL DISTRIBUTION

TO MUNICIPALITIES OR CONTRACTORS

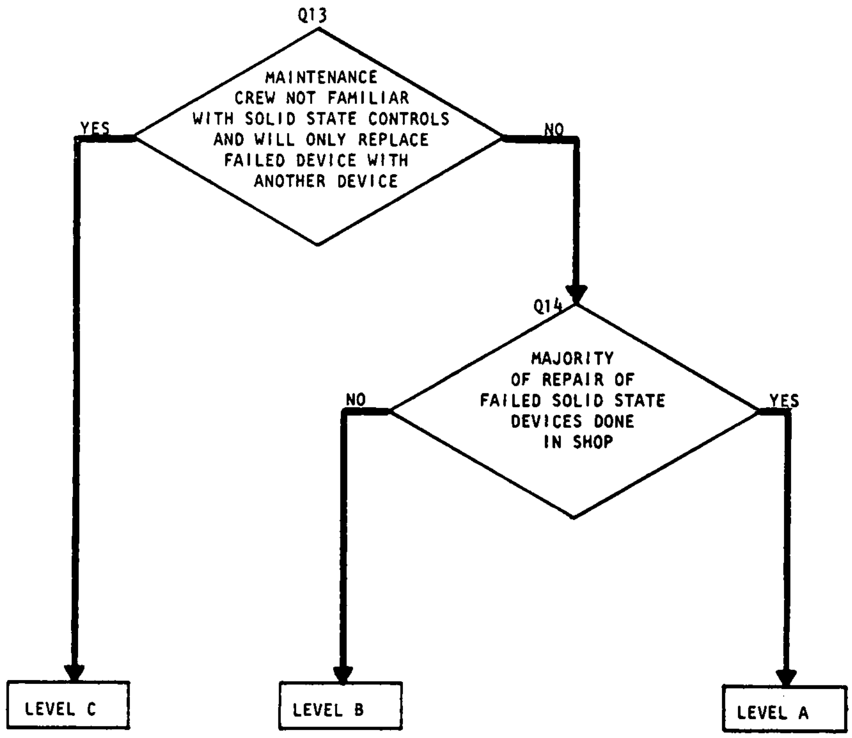
SECTION A

RESPONSE MAINTENANCE - REPAIR CLASSIFICATION



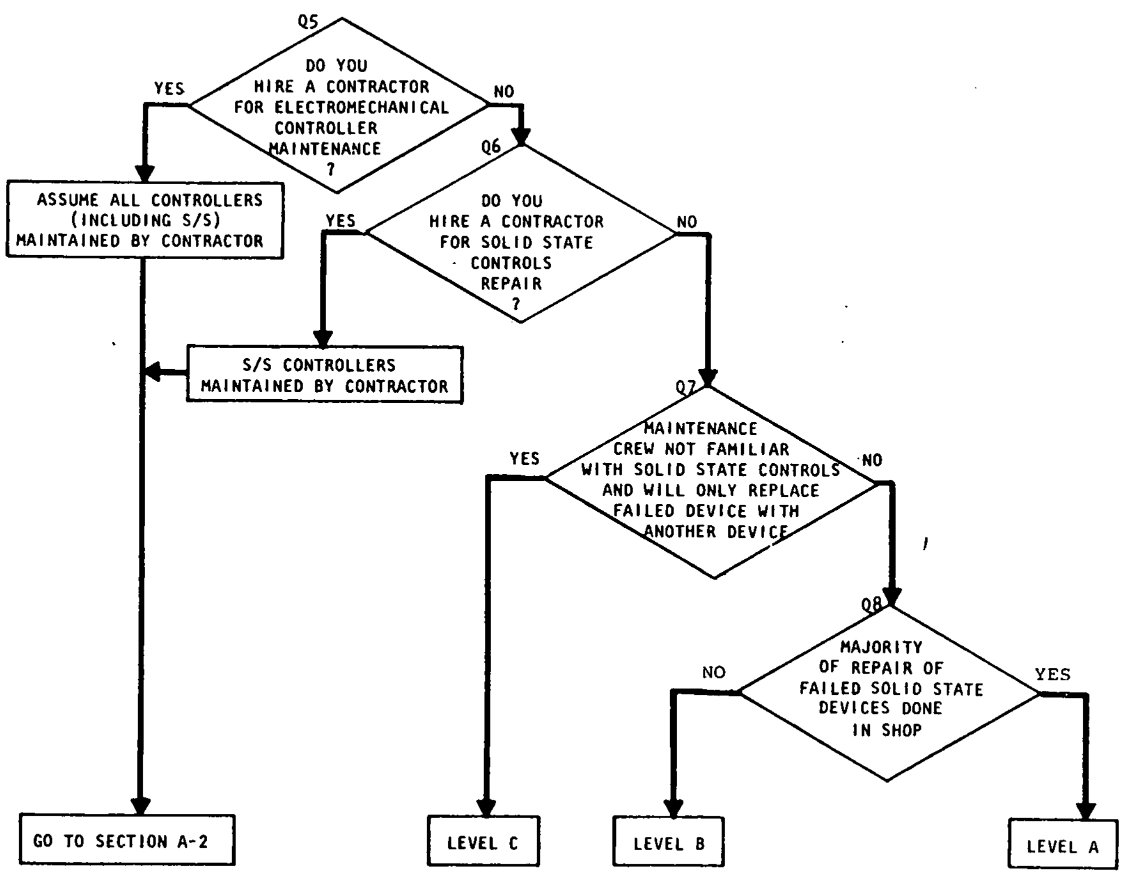
SECTION A-2

LEVEL OF RESPONSE MAINTENANCE FOR CONTRACTOR



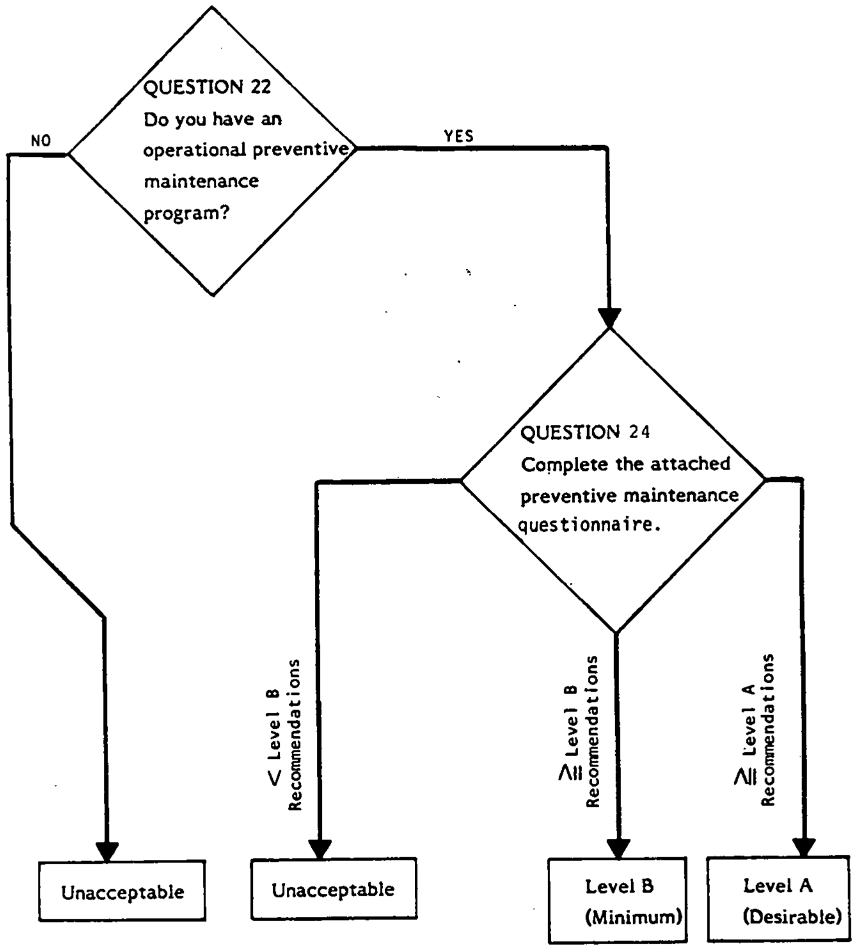
SECTION A-1

LEVEL OF RESPONSE MAINTENANCE



SECTION B

PREVENTIVE MAINTENANCE



RESPONSE MAINTENANCE

IF THE ANSWER TO QUESTION 17 IS YES, EVALUATE ALL ANSWERS IN THE CHECKLIST IN COMPARISON TO THE RECOMMENDATIONS AND IDENTIFY THE PROBABLE REASON FOR THE DELAY:

1. INADEQUATE MANPOWER
2. LACK OF TRAINED PERSONNEL
3. INADEQUATE LIST AND SERVICE EQUIPMENT
4. INADEQUATE BACKUP INVENTORY
5. INADEQUATE DOCUMENTATION AND/OR RECORD KEEPING
6. DELAY IN COMMUNICATIONS
7. INADEQUATE CONTRACTOR SERVICES

RECOMENDATIONS:

____

____

____

____

____

____

____

____

____

____

____

____

SECTION B

PREVENTIVE MAINTENANCE

Evaluate all answers in the preventive maintenance Questionnaire in comparison to the recommendations and identify the exact reason.

It should be noted that Level B includes the minimum requirements for the safe operation of intersection control equipment and signals. The answers must equal or exceed the recommendations or be termed unacceptable and be corrected by the municipality.

RECOMMENDATIONS: ____________________

____

____

____

____

FIELD SAMPLE VERIFICATION: ____________________

____

____

____

____

____

____

____

____

____

____

____

SECTION C. MAINTENANCE COST

DIVIDE THE BUDGET (Q2) ____________ BY THE TOTAL NUMBER OF INTERSECTIONS (Q1) ____________

MAINTENANCE COST/INTERSECTION $____________

COMPARE THE MAINTENANCE COST TO THE MAINTENANCE COST COMPUTED FROM THE CHECKLIST.

GENERAL

A. WITH THE EXISTING NUMBER OF INTERSECTIONS CAN THE OPERATIONAL CONDITIONS (E.G., MANPOWER, BACKUP EQUIPMENT, TEST FACILITIES) OR THE OPERATIONAL COST BE IMPROVED BY

	YES	NO
1. HIRING A CONTRACTOR FOR OVERALL MAINTENANCE.		
2. HIRING A CONTRACTOR FOR RESPONSE MAINTENANCE OF SOLID STATE DEVICES.		
3. HIRING ( ) MECHANIC(S).		
4. HIRING ( ) TECHNICIAN(S).		
5. HIRING ( ) SIGNAL SPECIALIST(S).		
6. INCREASING BACKUP INVENTORY.		
7. INCREASING TEST EQUIPMENT.		

B. IF A NEW SYSTEM IS TO BE INSTALLED:

1. THE MUNICIPALITY IS CAPABLE OF MAINTAINING THE EQUIPMENT ASSOCIATED WITH THE NEW SYSTEM.

2. IF ANSWER TO 1 IS "NO", LIST THE MINIMUM REQUIREMENTS AND POSSIBLE RECOMMENDATIONS:

C. ANY ADDITIONAL RECOMMENDATIONS:

APPENDIX F

SPECIFICATIONS FOR CONTRACT MAINTENANCE

The following material comprising Appendix F, the Contractor Specifications, was obtained from Edwards and Kelcey, Inc., Maintenance of Traffic Signal Systems (13). The report was prepared in 1981 for the Pennsylvania Department of Transportation.

Upon evaluation of the capabilities and requirements of a municipality, the maintenance of traffic signals and control equipment may be assigned (let) to a private contractor. The following recommendations may be included in the scope of work outlined in the contractual agreement:

1. **Preventive Maintenance** Level A or Level B as outlined in Preventive Maintenance Summary shall be performed by the contractor. This contract may be on a yearly basis. Material for the preventive maintenance may be supplied either by the municipality or the contractor.

2. **Response Maintenance** shall be performed by the contractor on a per call basis. Upon notification of failure of an intersection signal or control by the Municipal Engineer/Police, the contractor shall dispatch qualified personnel to the location within an agreed upon limit of time, to identify the problem and take proper measures. The intersection failure shall be corrected by the end of the next working day.

   Various contractor maintenance options are available to the municipality and are depicted in Figure 1. The municipality should choose an option which is compatible with their individual requirements.

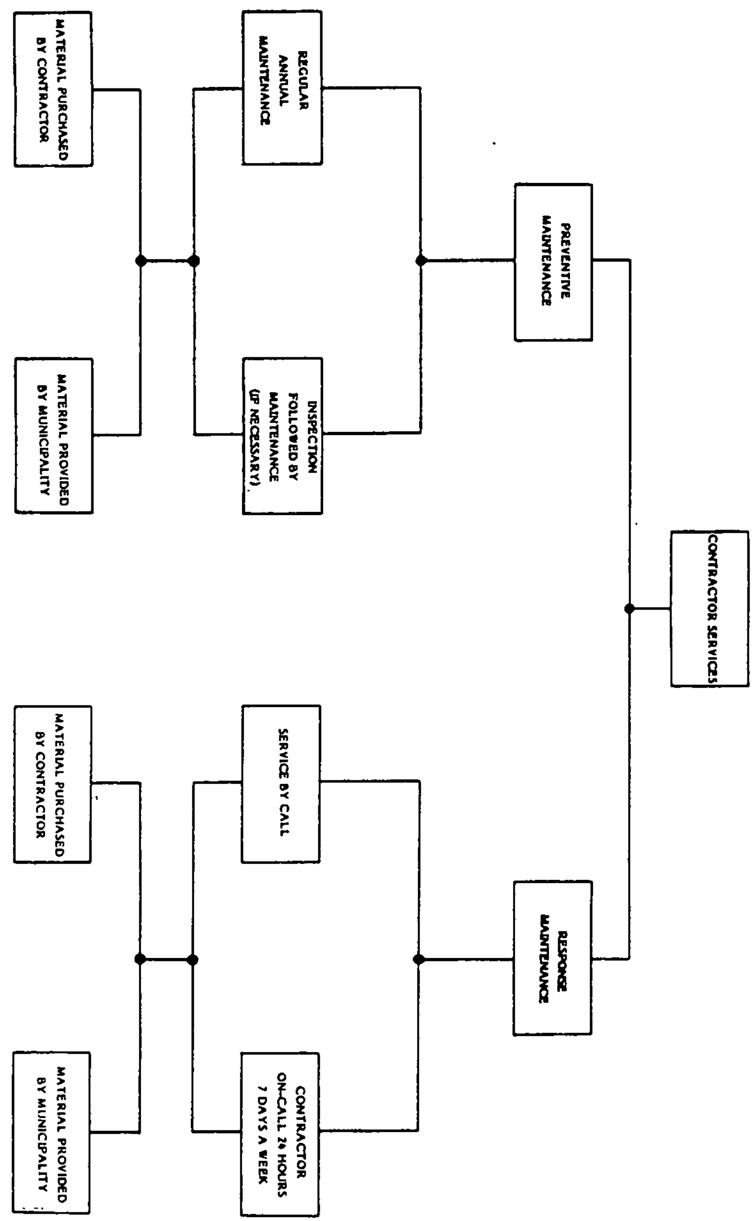


Figure 1

Contractor Maintenance Options

CONTRACTOR SPECIFICATIONS

GENERAL PROVISIONS

Work To Be Performed

The work to be performed shall include preventive and/or response maintenance at the locations designated. The attached addendum includes the estimated total number of hours required for preventive maintenance for each intersection.

New Installation, Increased or Decreased Quantities

Whenever the quantity of work listed in the attached addendum is increased or decreased due to addition or deletions of installations, the Municipality will notify the Contractor in writing. This notification shall give the following information: (1) A description of the installation, unit or item to be added or removed, (2) the location of the installation, unit, or item, and (3) effective date of change.

Additional Awards of Contracts

The Municipality may undertake or award other contracts for additional work. The contractor shall cooperate fully with such other contractors and Municipal employees and fit his own work to such additional work as may be directed by the Engineer. The contractor shall not commit or permit any act which will interfere with the performance of work by any other contractor or by Municipal employees.

The Municipality also reserves the right to solicit and award contracts for the purchase of materials to be used by the contractor, when determined to be in the best interest of the Municipality. The Contractor shall be allowed one (1) hour at the lowest Hourly Repair Charge rate for obtaining and transporting the materials from the Municipal shop.

Inspection

The Municipality reserves the right to assign an inspector to the contractor's operation for the purpose of determining compliance with the specifications and maintaining records, including the time records for service charges. Any work or materials found to be substandard or not in accordance with the provisions of this contract shall be repaired or replaced to the satisfaction of the Municipality at the sole expense of the contractor.

Work Performance

It shall be the contractor's responsibility to insure that he does not damage any material, equipment or structure during his operations, and he shall be held liable for any damage that he causes. If the contractor damages any materials, equipment or structure, he shall repair or replace it to the satisfaction of and at no expense to the Municipality.

All electrical work shall meet the electrical regulations of all state and local codes and otherwise as contained in the latest edition of the National Electrical Code of the National Board of Fire Underwriters.

All work shall be performed in a neat and workman-like manner. All material or equipment replaced shall be held available for inspection by the Municipality prior to disposal by the contractor.

Maintenance and Protection of Traffic

The maintenance and protection of traffic during preventive maintenance shall be the responsibility of the contractor in accordance with Bulletin 43 and/or PDT

Publication 90 of the Pennsylvania Department of Transportation. the contractor will be allowed to close one (1) lane of traffic, when necessary to provide the service required under this proposal, between the hours of 9:30 AM and 3:30 PM Monday through Friday, except holidays.

Damaged Parts, Materials and Equipment

Surplus or damaged parts, materials or other equipment which are salvageable shall be taken by the contractor to a place designated by the Municipality unless indicated otherwise. Any damaged poles, broken concrete, or other such materials that cannot be repaired shall be disposed of by the contractor.

Method of Payment

The method of payment shall conform to the type of maintenance performed as outlined in the agreement.

Transportation

The contractor shall be responsible for providing transportation. There shall be no additional charge for transportation.

Test Equipment and Tools

The contractor shall provide all the necessary test equipment and tools as listed in the Pennsylvania Department of Transportantion Suggested List of Equipment Requirements.

PREVENTIVE MAINTENANCE

Description of Work

Level preventive maintenance as outlined by the Pennsylvania Department of Transportation shall be provided. All records and documentation shall be maintained as part of the contract.

Materials Supplied

The contractor shall procure all material required for maintenance of the signal and control equipment.

Methods of Payment

The estimate of total maintenance cost (less material) submitted in the bid or prepared by the Municipality shall be paid monthly upon receipt of a detailed report of work performed.

A separate invoice detailing the material shall be submitted to the Municipality.

RESPONSE MAINTENANCE

Description of Work

The contractor shall designate in writing an emergency telephone number where he may be contacted concerning response on-call service. The contractor shall be on-call twenty-four (24) hours seven (7) days a week including holidays, for the purpose of making repairs. When a system or installation is not in operation or illuminated due to equipment failure or external damage, an authorized person (Engineer, Chief of Police) will notify the contractor of such failure. The contractor shall respond to correct the failure within a specified response time.

The response time for the contractor is classified into the following categories:

1. When notification is received between 7 AM - 4PM Monday to Friday.
   The response time shall be no more than one hour.
2. When notification is received any other time or day.
   The response time shall be no more than four hours.
3. Emergency or dangerous situation exists, in which case the contractor shall immediately dispatch qualified personnnel to eliminate such conditions.

   The contractor shall restore normal operation in the field within 24 hours. In the event the contractor is unable to restore normal operation in the field, a substitute controller shall be supplied at no additional cost to the Municipality until repairs to the existing controller can be made. Prior to the substitution, approval shall be granted by the Municipality. The existing controller shall be repaired and returned to the field in no more than fifteen (15) days.

   All repairs and testing of the failed equipment shall be done by the contractor.

   Complete record of the work performed and log-in sheet of the intersection shall be completed.

Material

All material for the repair shall be supplied by the contractor.

Method of Payment

Payment shall be made at the contract price per unit/hour for the respective item.

There will be a monthly service charge of _________ for the 24-hour on-call service.

In addition there shall be a minimum service charge per call of two hours, regardless of the actual time spent.

The service charge time shall include only that time spent in repairing or restoring the installation. No compensation will be paid for break periods or down time.

A detailed description of the work performed and the material replaced shall be submitted with the bill.

A separate invoice detailing the material shall be submitted to the Municipality.

PENALTIES

If the contractor response time exceeds the time as outlined in the previous section, a penalty of _______ per each additional hour will be charged. If the contractor response time exceeds by eight hours of the agreed upon limit, another contractor will be notified to repair the failed intersection at the expense of the original contractor. The Municipality shall deduct this amount from the contractor's monthly billing.

STANDARD PAY ITEMS

1. Response Maintenance

   a. Hourly Repair Charge $ /HR

   b. Hourly Overtime/Holiday Repair Charge $ /HR

   c. Monthly Service Charge $ /MONTH

2. Preventive Maintenance

   a. Hourly Repair Charge $ /HR

Payment for material shall be at the invoice price plus shipping cost.

Table 1

LIST OF INTERSECTIONS INCLUDED IN MAINTENANCE CONTRACT

INTERSECTION NAME	TYPE OF EQUIPMENT				MUNICIPALITY	COUNTY	PREVENTIVE MAINTENANCE LEVEL (HOURS)	RESPONSE MAINTENANCE HOURS
	E/M	A	S/S	MODEL				
						TOTAL		

APPENDIX G

PROCEDURE FOR SHOP TESTING OF TUNGSTEN FILAMENT LAMPS

Tungsten filament lamps such as those used in traffic signals have a well established pattern of life expectancy based on applied voltage in excess of rated voltage. This allows the potential life expectency of several brands to be compared in a relatively short period of time using equipment commonly available.

Tests to standards can be done as well but a highly stable power supply and a certified volt meter are needed. Since the conditions at signals typically include electrical noise and varying voltage, the comparison tests is somewhat more realistic. Vibration and external temperature extremes are not included in this test procedure.

As a matter of practice, we include a sample of the lamps currently being purchased to determine if the new offerings are comparable.

Testing has shown that significant differences exist between brands claiming 8000 hr. life. For example, we normally relamp every third year.

In order to conduct a valid test, several parameters must be observed:

1. Lamps must not materially heat each other.
   A. Spacing between lamps at least 9 in.
   B. Mounting panel must not reflect heat or it must reflect heat evenly.
2. Terminal voltage must be exactly the same at every lamp to the fraction of a volt.
3. Upon failure, arcing often occurs. Each lamp must be independently fused to eliminate any resulting transients.
4. The applied voltage must be a pure sine wave that is applied slowly from rated voltage to the selected excess voltage.
5. The lamps should be in their normal burning position.

The electrical components comprise:

1. An autotransformer with a stepless output of 0 to 240 volts. The current rating should be oversized by at least 25% so that the failure of lamps will not cause a significant rise in output voltage.
2. A contactor interlocked with the transformer voltage control to prevent the system from being turned on if the transformer is not set to zero volts and to turn the system off if the input voltage is interrupted by any external problem such as a storm.
3. Individually fused lamp holders. The holders must be heat resistant and strong.
4. A mounting rack designed to provide exactly the same voltage to every socket under all conditions. (We used 1 in. copper buss bars silver soldered in a pattern that provides two current paths to each socket. The open cage design prevents reflected heat problems.)
5. The power wire and the neutral wire are connected at opposite corners of the cage to minimize internal voltage drops.
6. A volt meter.

The cage is sized to allow five lamps of up to four brands to be tested at the same time.

The procedure is:

1. Install lamps and burn in for 25 hours at 120 volts to eliminate early failures. Replace as necessary. Continue until all lamps have burned 24 hours or a total of 36 hours from the start of the test have elapsed.
2. Turn on system and operate for one minute at rated voltage. Raise slowly to test voltage range of 140 to 160 volts. Too high a voltage results in internal arcing. Test voltage must be kept below that point.
   If this step is skipped, lamps will probably explode.
3. Review every ½ hour to record failures. (We test during working hours only. Early in the test when failures are few or failures will quickly eliminate a sample, the lamps can be allowed to burn continuously.)
4. Continue the test until a conclusion can be drawn. Since five samples of each brand are used, the test normally continues until all lamps fail.

A rating factor is developed for each sample from the average burning time of the sample. That factor is applied to the cost of the lamps to determine the relative Average User Cost. Since the Average User Cost depends on the cost of labor and vehicles as well as the user's emergency replacement policy, each jurisdiction must derive its own formula.

In our case, some signals are in excess of 30 miles from the signal shop and we must take all lamp calls received during off duty hours no later than the next daylight period; the cost of the lamp is insignificant.

Source: Mr. Raymond S. Pusey, Chief Traffic Engineer, State of Delaware D.O.T., Division of Highways, December, 1983.

APPENDIX H

EXAMPLE SPECIFICATION FOR MAINTENANCE-TRAINING TO BE FURNISHED BY EQUIPMENT SUPPLIER

1.21 TRAINING

1.21.1 General

The CONTRACTOR shall provide formal classroom training and operations training for personnel to be designated by the ENGINEER. Training schedules, course outlines, and instructor resumes for each course shall be submitted 30 days in advance by the CONTRACTOR for approval by the ENGINEER. The course outline shall contain a complete description of the course content which shall include all materials to be presented in the class and/or laboratory. A class schedule showing what will be taught each day and a copy of the course materials to be given each person attending the class shall be submitted with the class schedule and outline. The CONTRACTOR shall provide training on the computer system, the field equipment, and the "control" software being supplied as described below. The dates for each school shall be subject to approval by the ENGINEER. Unless otherwise specified herein, each training course shall be for a maximum of 12 persons designated by the ENGINEER. Fifteen copies of all course materials for each training course shall be supplied and will be retained by the State. The training for each course shall be provided by qualified instructors in formal classroom and/or laboratory presentations.

The training to be conducted by the CONTRACTOR shall not be conducted concurrently or with overlapping time periods. The CONTRACTOR shall bear all costs associated with the training to be supplied under this contract except costs associated with transportation, food, and lodging of personnel attending the training courses.

1.21.2 Computer Training

A computer training course shall be held for a maximum of six persons at the computer manufacturer's facility. The course shall be a minimum of 80 hours in duration and shall cover all of the following aspects:

- o Computer instruction set and use.
- o Use of real-time operating system.
- o System generation procedure for the real-time operating system.

All costs associated with this training course except transportation, food, and lodging for those attending the course, shall be the responsibility of the CONTRACTOR. Any tuition or books required by this course shall be supplied by the CONTRACTOR as part of this contract. This training shall be completed no later than 60 days prior to the beginning of the system operating tests.

1.21.3 Maintenance Training

A maintenance training course shall be provided in Durham, North Carolina in facilities provided by the State. The course shall provide at least 80 hours of instruction, and shall consist of the following as minimum requirements:

1. Forty hours of class room training on the maintenance of all field equipment being supplied by the CONTRACTOR.
2. Forty hours of laboratory training on the maintenance of all field equipment being supplied by the CONTRACTOR. At a minimum, this laboratory training shall include actual work on the controllers, communications equipment, detectors, conflict monitors, and any additional field hardware supplied by the CONTRACTOR.

This training shall be completed no later than 30 days prior to the beginning of system operating tests.

1.21.4 Software Training

A software training course shall be provided in Durham, North Carolina in facilities provided by the State. This course shall be at least 80 hours in duration and shall consist of all aspects of the system software. This training shall include, as a minimum, the following items:

1. A minimum of 40 hours of classroom training shall be provided on the operation of all elements of the system, such as the system controls, displays and operational procedures, with special attention given to equipment and energizing procedures, input/output procedures, display format and utilization, utilization of operator controls and emergency procedures.
2. A minimum of 40 hours of laboratory training shall be provided where each person in the class is given the opportunity to operate the computer system and to demonstrate on the system each item taught in class.

This training shall be completed no later than 30 days prior to the beginning of the System Operating Tests.

1.21.5 User Orientation and Familiarization

During the period from the start of the computer installation until the end of the Observation Period, the CONTRACTOR shall provide "hands on" training to the State and City personnel assigned to the project. This training shall be in addition to other training requirements specified herein.

During this training, the personnel designated by the ENGINEER shall perform at least the following activities and be made thoroughly knowledgeable in the procedures involved by actually performing each such procedure under supervision.

This training shall include but not be limited to:

1. Becoming completely familiar with construction details of central facility (location of disconnects, distribution panels, cable routings, etc.).
2. Learning how to load paper, change ribbons, load cards, mount tapes, etc., into peripherals.
3. Learning how to enter on-line commands (security code, formats, explanation of parameters).
4. Learning data card formatting and what each parameter is used for.
5. Learning data loading peculiarities (i.e., use of blank cards, if required).
6. Learning operation of all devices (computer start-up, disk, printer, etc.).
7. Learning preventive maintenance procedures for all devices (written and demonstrated).
8. Learning procedure for bringing intersections and detectors on-line for the first time, as well as for deleting intersections and detectors.
9. Becoming familiar with procedures to expand the display map (demonstrated).
10. Becoming familiar with procedures to expand the communications system.
11. Becoming familiar with device capabilities (can card reader speed be changed? Does system have flash capability?).
12. Learning to perform and understand all diagnostic tests for each device.
13. Learning basic troubleshooting procedures to isolate problems to either hardware or software.
14. Learning basic operator functions on a periodic basis, such as disk saves, and data base management.
15. Receiving instructions and actual experience in the use of utility routines (compile, link, edit).
16. Learning procedure for adding more cable and splicing procedures to complete the line back to the central facility.

Source: Benton G. Payne, Signal Systems Engineer, North Carolina D.O.T., Division of Highways, Traffic Engineering Branch, January, 1984.

APPENDIX I

DETAILS OF CINCINNATI'S COMPUTERIZED REPORTING

DESCRIPTION OF TRAFFIC CONTROL

EQUIPMENT MAINTENANCE SUMMARY

Exhibit #1 is the radio dispatcher's log. This dispatcher receives all complaints and dispatches all repair crews. When receiving a call and dispatching a crew, he fills out the items, identified by a solid underline. When the crew calls back with their findings and repair activity, he fills out the items underlined with short dashes. Once a week, the dispatcher sends all completed logs to the engineering office where the remaining items are coded for computer input. This coding is taken from Exhibit #2.

Exhibit #2 is a computer alpha numeric code for the most commonly used words in the log. A clerk fills out the coding and sends it to EDP.

On a quarterly basis, EDP sends back several reports. These reports contain the malfunctions from the previous four calendar quarters. The report that contains one complete calendar year is filled permanently for historical and legal purposes.

Exhibit #3 is the standard report. Larger cities will generate a bulky report and it is helpful to develop a chronic problem list to help pinpoint trouble spots. This is Exhibit #4. This report is generated by listing all intersections which have had more than twenty complaints in the last four calendar quarters and three or more complaints in the last reported month. This report is distributed to the maintenance section with instructions to place special maintenance attention on these locations. On occasion, they find that the problem is caused by inadequate design and it is referred to the design section for attention.

Using a computorized intersection equipment inventory, and cross referencing it with the data which compiled Exhibit #3, we can readily compile a component failure list as shown in Exhibit #5.

Finally, at the end of each component list is a failure ratio. The formula (Exhibit #6) is such that a failure ratio equal to 1.0 indicates normal performance and a failure ratio of 2.0 would indicate twice as many malfunctions as a normal component, etc.

10/14/75

CGF/jm

Source: Ben W. McKay, P.E., Principal Traffic Engineer, City of Cincinnati Department of Public Works, Division of Traffic Engineering, Cincinnati, Ohio, May, 1984.

Page 1 14 Tuesday 2/21/84

DISPATCHER'S LOG

CITY OF CINCINNATI
DIVISION OF TRAFFIC ENGINEERING

REC'D FROM	REC'D CODE (1-3)	DATE MO DA YR (4-8)	TIME HR MIN AP (9-13)	EDS LOC NO (14-17)	LOCATION (18)	DIR.	TROUBLE (19-38)	REF'D TO (40-42)	TIME HR MIN AP (43-47)	OK'D BY (48-50)	TIME HR MIN AP (51-55)	EDS REP'D (56-58)	CODE FOUND (60-64)	TROUBLE FOUND (65-80)
METRO		02 21 4	0700 A	B069	Blair & Gilbert		Stuck – Red	193	0700 A	R Ba	0820 A	936	-4--1	Repl. Controller
	117		0730 A	E078	Edon Pk Cnt. @ Florence		Stuck	193	0755 A	R B	0830 A	936	-4US1	Repl. Amber-Timer
Linwood School			0800 A	E706	4900 Eastern Linwood School		Walk Out	173	0800 A	WR	0930 A			1-(a)14
~~C/E~~			[illegible] 54 A		~~7866 Greentown~~		~~St. Lt. Out~~	173	1530 P	LTW	1650 P			~~C & E~~
	111		0845	A029	Mitchell @ So. Grove	SB	Red	173	0845	WR	1300 P	830	-3LA1	1-544
	″		″	F050	Gray. @ Winton		Red Out – Gray	″	″	WR	1320 P	[illegible]30	-3LA1	1-544
	117		0900 A	E044	7th and Elm	NB	Red	173	0900 A	WR	1000 A	130	-3LA1	1-544
	160		0920 A	E026	8th and Plum	EB	Red	173	0920 A	WR	1015 A	230	-3LA1	1-544
	135		1010 A	R020	Rh Isl. @ Seymour	NB	Red	173	1010 A	WR	1130 P	130	-3LA1	1-544
City			1051 A	E013	Madison & Edwards	NE	Red out of focus	173	1051 A	WR	1130 A	611	-1--5	Re focused
~~City~~			1055 A		~~[illegible] History Pky~~		~~St Lt Out~~	173	1530 P	CT	[illegible]			~~[illegible]~~
City			1115 A	F063	1st Race		Walk Out	173	1207 P	WR	1400 P	N10	-1--P	Not Out
	55R		1212 P	R004	3rd Race		Signal out of focus	173	1212 P	WR	1415 P	N11	-1--5	Refocused
	147		1346 P	L703	[illegible] of Sorrows		[illegible] flashers out	173	1530 P	LTW	1750 P	9F0	-F1W7	Reset clock

EXHIBIT #1

CITY OF CINCINNATI
DIVISION OF TRAFFIC ENGINEERING

DISPATCHER'S LOG

COMPLAINTS REC'd by PHONE: REC'D FROM	RADIO CALL No. if REC'd by RADIO: REC'D CODE (1–3)	DATE MO (4–5)	DATE DA (6–7)	DATE YR (8)	TIME HR (9–10)	TIME MIN (11–12)	TIME AP (13)	INTERSECTION CODE NUMBER: EDS LOC (14–15)	EDS NO (16–17)	LOCATION (18)	DIR.	TROUBLE (19–38)	MAINTENANCE IDENTIFICATION: REF'D TO (40–42)	TIME REFERRED TO MAINTENANCE: TIME HR (43–44)	TIME MIN (45–46)	TIME AP (47)	INITIALS OF REPAIRER: OK'D BY (48–50)	TIME OF REPAIR: TIME HR (51–52)	TIME MIN (53–54)	TIME AP (55)	SEE EXHIBIT II: EDS CODE REP'D (56–58)	EDS CODE FOUND (59–64)	TROUBLE FOUND (65–80)
	118	Ø5	1Ø	3	Ø8	15	A	FØ	Ø5	FAIRMOUNT & HARRISON	NE CORN.	CYCLING ON PED WALK	183	Ø8	22	A	CGF	Ø8	55	A	635	2-Z1	PUSH BUTTON VANDALIZED REPLACED IT.

EEL-40-065

TRAFFIC [illegible] REPORT

ALPHA-NUMERIC CODES FOR DISPATCHER'S LOG

Exhibit II

COL. [illegible]	COL. 57	COL. 58	COL. 61	COL. 62	COL. 63	COL. 64	CODE
COMPLAINT			CORRECTION				
DIR.	EQUIPMENT	TROUBLE	EQUIPMENT	COMPONENT	TYPE	ACTION	
NORTH	PED. SIGNAL	OUT OF FOCUS	PED. SIGNAL	SCHOOL	WIRING	REPLACED	1.
EAST	PUSHBUTTON	DOWN	PUSHBUTTON	EMER. VEH.	LOOP	REPAIRED	2.
SOUTH	VEH. SIGNAL	LAG	VEH. SIGNAL	DOOR	RADAR	CLEANED	3.
WEST	CONTROLLER	TIMING	CONTROLLER		SONIC	ADJUSTED	4.
N.W.	DETECTOR	CYCLING	DETECTOR		PRESSURE	REFOCUSED	5.
N.E.	MAR. 1974	STUCK	MAR. 1974		MAGNETIC	RETIMED	6.
S.W.	SIGN	SKIPPING	SIGN	SWITCH		RESET	7.
S.E.	CABLE	FLASHING	CABLE			REFERRED	8.
ALL	OTHER	OTHER	OTHER			OTHER	9.
		OUT OF ORDER	NO TROUBLE		ARROW	NO ACTION	Ø.
				AMPLIFIER	RED		A.
				CIR. BREAKER	YELLOW		B.
				CONTACTS	GREEN	CLOSED	C.
		DAMAGED		DIAL UNIT	DONT WALK		D.
				BALLAST	WALK		E.
	FLASHER	FLICKERING	FLASHER	FUSE	FLASHING		F.
				LENS	NORMAL		G.
		HIT		RATCHET ASSY.	RECALL MAX.		H.
	ISLAND LIGHT		ISLAND LIGHT	CAM	RECALL MIN.	INFORMATION	I.
				CAM SHAFT	FLUSH MTD.		J.
				DIAL KEYS	CONE		K.
	LANE CNTRL.		LANE CNTRL.	LAMP	PEDESTAL		L.
		MISSING		MASTER	TRANSFORMR		M.
NONE				TUBE	110V		N.
		OUT		MODULE	LAG/OFFSET	INOPERATIVE	O.
	POLE		POLE	POLYPULSE	DIAL TRANSFER		P.
				SOCKET	MOTOR		Q.
	REVRSBL.LN.		REVRSBL.LN.	RELAY	ALL RED	REMOVED	R.
				SIGNAL	AMBER	SWITCHED TO	S.
				TRANSFRMR.	DUAL	TIGHTENED	T.
				TIMER	PEDESTRIAN		U.
				VISOR	VEHICLE		V.
				WIRING	CLOCK	WORKING ON	W.
				LOOP	(ACCIDENT)		X.
				RADAR			Y.
		VANDALIZED		[illegible]	(VANDALISM)		Z.

EXHIBIT #3

TRAFFIC SIGNAL MALFUNCTION REPORT

REPORT DATE 03/04/75

INTERSECTION LISTING

LOCATION	DATE		REPORTED			ACTION TAKEN			BY
EAST HILLS & MADISON	02/14/74 1712P		OTHER	LAG	OTHER			OTHER	WLB
EAST HILLS & MADISON	10/22/74 1526P		VEH SIGNAL	STUCK	DETECTOR	AMPLIFIER	LOOP	REPLACED	W B
EDEN PARK ENT & GILBERT	01/10/74 1125A		VEH SIGNAL	STUCK	VEH SIGNAL		NORMAL CYCLE	SWITCHED TO	D S
EDEN PARK ENT & GILBERT	02/22/74 0810A	E,	SIGN	OUT OF FOCUS	SIGNS			REFOCUSED	R B
EDEN PARK ENT & GILBERT	02/25/74 0820A		SIGN	OUT OF FOCUS	NO TROUBLE			NO ACTION	R F
EDEN PARK ENT & GILBERT	05/10/74 1015A		VEH SIGNAL	OUT				NO ACTION	LTW
EDEN PARK ENT & GILBERT	07/23/74 1350P	ALL	PED SIGNAL	OUT	CONTROLLER	FUSE		REPLACED	R F
EDEN PARK ENT & GILBERT	08/21/74 0942A	S,	VEH SIGNAL	OUT	VEH SIGNAL	LAMP	RED	REPLACED	R F
EDEN PARK ENT & GILBERT	08/22/74 1400P	S,	VEH SIGNAL	OUT	VEH SIGNAL	LAMP	RED	REPLACED	D H
EDEN PARK ENT & GILBERT	08/22/74 1502P	NE,	PED SIGNAL	OUT	CONTROLLER	TUBES		REPLACED	P M
EDEN PARK ENT & GILBERT	12/13/74 0500A		OTHER	OUT			NO ACTION		
EDWARDS & ERIE	01/25/74 1651P	NW,	PED SIGNAL	OUT OF ORDER	PED SIGNAL	TUBES	DONT WALK	REPLACED	JNY
EDWARDS & ERIE	06/06/74 1701P		VEH SIGNAL	OTHER	NO TROUBLE			PER CDS	J R
EDWARDS & ERIE	10/22/74 1331P	IN	VEH SIGNAL	OUT	VEH SIGNAL	LAMP	RED	REPLACED	R F
EDWARDS & MADISON	01/02/74 1326P	NW,	PED SIGNAL	OUT OF ORDER	PED SIGNAL	TUBES	WALK	REPLACED	JNY
EDWARDS & MADISON	01/10/74 0700A		VEH SIGNAL	TIMING	NO TROUBLE			NO ACTION	D S
EDWARDS & MADISON	02/04/74 0821A		VEH SIGNAL	TIMING	NO TROUBLE			PER CDS	D S
EDWARDS & MADISON	02/07/74 1507P		VEH SIGNAL	STUCK	CONTROLLER	DIAL UNIT		REPLACED	W B
EDWARDS & MADISON	02/07/74 1905P		VEH SIGNAL	STUCK	CONTROLLER		REPLACED		W B
EDWARDS & MADISON	02/08/74 1527P		VEH SIGNAL	CYCLING			NO ACTION		
EDWARDS & MADISON	02/14/74 1455P		VEH SIGNAL	STUCK	CONTROLLER	DIAL UNIT	MOTOR	REPLACED	W B
EDWARDS & MADISON	02/21/74 0855A		VEH SIGNAL	CYCLING	CONTROLLER		REPLACED	DIAL TRANS,	C B
EDWARDS & MADISON	02/22/74 0855A		VEH SIGNAL	TIMING	CONTROLLER		SWITCHED TO	NORMAL CYCLE	C R
EDWARDS & MADISON	04/03/74 0925A	OUT	VEH SIGNAL	OUT	VEH SIGNAL	LAMP	GREEN	REPLACED	D H
EDWARDS & MADISON	04/09/74 0845A	SE,	PED SIGNAL	OUT				NO ACTION	R F
EDWARDS & MADISON	04/29/74 0845A	NW,	PED SIGNAL	OUT	PED SIGNAL			REFOCUSED	R F
EDWARDS & MADISON	06/12/74 1707P	OUT	VEH SIGNAL	TIMING	NO TROUBLE			NO ACTION	WB
EDWARDS & MADISON	06/13/74 1539P		VEH SIGNAL	STUCK	CONTROLLER	DIAL UNIT	MOTOR	REPLACED	W B
EDWARDS & MADISON	06/24/74 1436P	E,	VEH SIGNAL	OTHER	NO TROUBLE			PER CDS	W B
EDWARDS & MADISON	08/18/74 1150A		PED SIGNAL	STUCK	CONTROLLER	FUSE		REPLACED	R F
EDWARDS & MADISON	08/19/74 1100A		PED SIGNAL	OUT	CONTROLLER		RELAY	REPLACED	R F
EDWARDS & MADISON	08/29/74 0835A	SW,	PED SIGNAL	OUT	CONTROLLER	TRANSFORMER	DONT WALK	REPLACED	D H
EDWARDS & MADISON	09/25/74 1745P		VEH SIGNAL	OTHER			NO ACTION		
EDWARDS & MADISON	10/23/74 1242P	ALL	VEH SIGNAL	OUT			WORKING ON		DWS
EDWARDS & MADISON	10/24/74 0827A	W,	VEH SIGNAL	OUT	VEH SIGNAL	LAMP		TIGHTENED	

EXHIBIT #4

TRAFFIC SIGNAL MALFUNCTION REPORT

PAGE 2

REPORT DATE 02/23/74

CHRONIC PROBLEMS

LOCATION	DATE			REPORTED			ACTION TAKEN			BY
HARRISON AV & MCHENRY AV	01/08/73	0820	E,	VEH SIGNAL	OUT OF ORDER	VEH SIGNAL	LAMP	GREEN	REPLACED	L W
HARRISON AV & MCHENRY AV	01/18/73	1615P	W,	VEH SIGNAL	OUT OF ORDER	CONTROLLER	CONTACTS		REPLACED	W B
HARRISON AV & MCHENRY AV	01/30/73	1340P	SW,	PED SIGNAL	OUT OF FOCUS	PED SIGNAL			REFOCUSED	LTW
HARRISON AV & MCHENRY AV	03/11/73	1021A	ALL	VEH SIGNAL	STUCK	OTHER			OTHER	R L
HARRISON AV & MCHENRY AV	03/11/73	1730P	ALL	VEH SIGNAL	STUCK	VEH SIGNAL			REFOCUSED	D E
HARRISON AV & MCHENRY AV	03/16/73	1510P	ALL	VEH SIGNAL	STUCK					W B
HARRISON AV & MCHENRY AV	03/16/73	1617P	ALL	VEH SIGNAL	STUCK	CONTROLLER	DIAL UNIT		CLEANED	W B
HARRISON AV & MCHENRY AV	03/19/73	2350P		PED SIGNAL	OUT OF ORDER	PED SIGNAL	LAMP		REPLACED	JRP
HARRISON AV & MCHENRY AV	05/30/73	0830A	SW,	PED SIGNAL	OUT OF ORDER	PED SIGNAL	LAMP	DONT WALK	REPLACED	LTW
HARRISON AV & MCHENRY AV	06/11/73	1000A	S,	VEH SIGNAL	TIMING	CONTROLLER	CONTACTS		REPLACED	TOU
HARRISON AV & MCHENRY AV	06/14/73	0815A	S,	VEH SIGNAL	TIMING	DETECTOR	AMPLIFIER LOOP		REPLACED	TOU
HARRISON AV & MCHENRY AV	06/14/73	1544P	S,	VEH SIGNAL	OUT OF ORDER	NO TROUBLE			NO ACTION	W B
HARRISON AV & MCHENRY AV	06/26/73	1050A	W,	PED SIGNAL	OUT OF ORDER	PED SIGNAL	LAMP	WALK	REPLACED	LTW
HARRISON AV & MCHENRY AV	07/24/73	0835A	SW,	PED SIGNAL	OUT OF ORDER	PED SIGNAL	LAMP	DONT WALK	REPLACED	LTW
HARRISON AV & MCHENRY AV	08/09/73	2117P		PED SIGNAL	OUT OF ORDER	PED SIGNAL	LAMP	DONT WALK	REPLACED	D H
HARRISON AV & MCHENRY AV	09/05/73	1105A	NE,	PED SIGNAL	OUT OF ORDER	PED SIGNAL	LAMP		REPLACED	LTW
HARRISON AV & MCHENRY AV	09/18/73	2144P	E,	VEH SIGNAL	OUT OF ORDER	VEH SIGNAL	ARROW	RELAY	REPLACED	W B
HARRISON & MCHENRY	10/30/73	0725A	S,	VEH SIGNAL	OUT OF ORDER	VEH SIGNAL	LAMP	GREEN	REPLACED	R F
HARRISON & MCHENRY	10/31/73	0730A	NW,	VEH SIGNAL	OUT OF ORDER	VEH SIGNAL	LAMP	GREEN	REPLACED	R F
HARRISON & MCHENRY	11/26/73	1535P	NW,	PED SIGNAL	OUT OF ORDER	PED SIGNAL	LAMP	DONT WALK	REPLACED	D H
HARRISON & MCHENRY	11/30/73	1701A		PED SIGNAL	STUCK	NO TROUBLE			NO ACTION	W B
HARRISON & MCHENRY	12/11/73	0125A		SIGN	OUT				NO ACTION	
HARRISON & MCHENRY	12/25/73	2035P		VEH SIGNAL	STUCK	NO TROUBLE			OTHER	DWS
HARRISON & MCHENRY	12/28/73	0915A	IN	VEH SIGNAL	OUT OF ORDER	VEH SIGNAL	LAMP	GREEN	REPLACED	LTW

EXHIBIT #5

TRAFFIC SIGNAL MALFUNCTION REPORT

REPORT DATE 03/04/75

COMPONENT LISTING

COMPONENT	MAKER		MODEL		CODE	ACTION TAKEN		LOCATION	DATE
DETECTOR	AUT SIG	L	D2		619	AMPLIFIER LOOP	REPLACED	01 614 AUTO-SIG LD1	03/26/74
DETECTOR	AUT SIG	L	D2		619	AMPLIFIER LOOP	REPLACED	BEEKMAN & ELMORE	04/03/74
DETECTOR	AUT SIG	L	D2		619		REPLACED	BEEKMAN & ELMORE	11/20/74
DETECTOR	AUT SIG	L	D2		619	LOOP	REPLACED	CENTER HILL & NORTH BEND	03/07/74
DETECTOR	AUT SIG	L	D2		619	RELAY	REPLACED	CENTER HILL & NORTH BEND	05/06/74
DETECTOR	AUT SIG	L	D2		619	AMPLIFIER LOOP	REPLACED	EAST HILLS & MADISON	10/22/74
DETECTOR	AUTO-SIG	L	D2		619	AMPLIFIER	REPLACED	FAIRMONT & HARRISON	08/05/74
DETECTOR	AUT SIG	L	D2		619	AMPLIFIER	ADJUSTED	HACKBERRY & MADISON	08/28/74
DETECTOR	AUT SIG	L	D2		619	AMPLIFIER LOOP	ADJUSTED	HARRISON & MCHENRY	01/10/74
DETECTOR	AUT SIG	L	D2		619	AMPLIFIER LOOP	REPLACED	HARRISON & MCHENRY	03/29/74
DETECTOR	AUT SIG	L	D2		619	AMPLIFIER	CLEANED	OAK & READING	07/25/74
DETECTOR	AUT SIG	L	D2		619	AMPLIFIER LOOP	REPLACED	QUEEN CITY & SUNSET	07/13/74

FAILURE RATIO = 1,35
TOTAL MODELS = 33
TOTAL FAILURES = 13

COMPONENT	MAKER		MODEL		CODE	ACTION TAKEN		LOCATION	DATE
DETECTOR	DECATUR	X	LMH		661	AMPLIFIER	ADJUSTED	GILBERT, HEWITT,MNTGMY;WOODBRN	09/09/74
DETECTOR	DECATUR	X	LMH	3	661	AMPLIFIER	ADJUSTED	GRANDIN, MADISON, TORRENCE PKY	05/08/74
DETECTOR	DECATUR	X	LMH	3	661	AMPLIFIER	ADJUSTED	GRANDIN, MADISON, TORRENCE PKY	09/14/74
DETECTOR	DECATUR	X	LMH	3	661	AMPLIFIER	REPLACED	GRANDIN, MADISON, TORRENCE PKY	10/30/74
DETECTOR	DECATUR	X	LMH		661	AMPLIFIER LOOP	ADJUSTED	IBSEN & MARBURG	12/06/74
DETECTOR	DECATUR	X	LMH		661	AMPLIFIER	ADJUSTED	LANGDON FM,RIDGEACRES & HIL DA	06/18/74
DETECTOR	DECATUR	X	LMH		661	AMPLIFIER	REPLACED	SECTION & SALFORD	12/09/74

FAILURE RATIO = 1,84
TOTAL MODELS = 13
TOTAL FAILURES = 7

COMPONENT	MAKER		MODEL		CODE	ACTION TAKEN		LOCATION	DATE
DETECTOR	AUT SIG	S	PDR1		818	AMPLIFIER	REPLACED	ASHTREE & HAMILTON	07/09/74
DETECTOR	AUT SIG	S	PDR1		818	AMPLIFIER SONIC	ADJUSTED	ASHTREE & HAMILTON	10/30/74
DETECTOR	AUT SIG	S	PDR1		818	AMPLIFIER SONIC	ADJUSTED	CAMBRIDGE & SUTTON	07/15/74
DETECTOR	AUT SIG	S	PDR1		818	AMPLIFIER SONIC	REPLACED	CAMBRIDGE & SUTTON	08/19/74
DETECTOR	AUT SIG	S	PDR1		818	AMPLIFIER SONIC	REPLACED	CAMBRIDGE & SUTTON	11/21/74
DETECTOR	AUT SIG	S	PDR1		818	AMPLIFIER SONIC	ADJUSTED	DRAPER & SPRING GROVE	06/18/74
DETECTOR	AUT SIG	S	PDR1		818	AMPLIFIER LOOP	REPLACED	KEBLER & WESTWOOD	03/18/74
DETECTOR	AUT SIG	S	PDR1		818	AMPLIFIER SONIC	ADJUSTED	MADISON & VISTA	02/06/74
DETECTOR	AUT SIG	S	PDR1	1	818	AMPLIFIER SONIC	ADJUSTED	PARK & TAFT	03/28/74
DETECTOR	AUT SIG	S	PDR1	3	818	AMPLIFIER SONIC	ADJUSTED	READING & SEYMOUR	01/30/74
							[illegible]	[illegible]	[illegible]

EXHIBIT # 6

$$\text{FAILURL RATIO} = \frac{\text{NO OF FAILURES FOR A SPECIFIC MODEL}}{\text{TOTAL NO OF FAILURES FOR ALL CONTROLLER/OR DETECTORS}} \times \frac{\text{TOTAL N OF CONTROLLERS/OR DETECTORS}}{\text{TOTAL NO FOR A SPECIFIC MODEL}}$$

TOTAL NO OF CONTROLLERS	639
TOTAL NO OF CONTROLLER FAILURES	1301
TOTAL NO OF DETECTORS	290
TOTAL NO OF DETECTOR FAILURES	130

THE TRANSPORTATION RESEARCH BOARD is an agency of the National Research Council, which serves the National Academy of Sciences and the National Academy of Engineering. The Board's purpose is to stimulate research concerning the nature and performance of transportation systems, to disseminate information that the research produces, and to encourage the application of appropriate research findings. The Board's program is carried out by more than 270 committees, task forces, and panels composed of more than 3,300 administrators, engineers, social scientists, attorneys, educators, and others concerned with transportation; they serve without compensation. The program is supported by state transportation and highway departments, the modal administrations of the U.S. Department of Transportation, the Association of American Railroads, the National Highway Traffic Safety Administration, and other organizations and individuals interested in the development of transportation.

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TRANSPORTATION RESEARCH BOARD
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ADDRESS CORRECTION REQUESTED

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