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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
SYNTHESIS OF HIGHWAY PRACTICE 166

TRAFFIC SIGNAL CONTROL EQUIPMENT: STATE OF THE ART

TRANSPORTATION RESEARCH BOARD
National Research Council

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TRAFFIC SIGNAL CONTROL EQUIPMENT: STATE OF THE ART

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TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL
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DECEMBER 1990

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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

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

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

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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 and others interested in the capabilities of currently available equipment for traffic signal control. Information is provided on functions and operations of controller assemblies, displays, detectors, communications, and computerized system masters.

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.

Traffic engineers need to know the functional capabilities of the various types of signal control equipment in order to select appropriate equipment for a specific application. This report of the Transportation Research Board describes the functions of each type of equipment and how it works, and gives advantages, disadvantages, and limitations.

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.

CONTENTS

ACKNOWLEDGMENTS

This synthesis was completed by the Transportation Research Board under the supervision of Robert E. Skinner, Jr., Director for Special Projects. The Principal Investigator responsible for conduct of the synthesis was Herbert A. Pennock, Special Projects Engineer. This synthesis was edited by Judith Klein.

Special appreciation is expressed to Peter J. Yauch, District Signal Systems and Safety Engineer, Florida Department of Transportation, who was responsible for the collection of the data and the preparation of the report.

Valuable assistance in the preparation of this synthesis was provided by the Topic Panel, consisting of Frank Deasy, Traffic Systems Engineer, Arlington County Department of Public Works; Paul H. Fowler, Automobile Club of Southern California (ret.); David R. Gibson, Highway Engineer, Federal Highway Administration; William W. McGuirk, Chief, Signal Design Branch, City of Washington Bureau of Traffic Services; Raymond S. Pusey, Chief Traffic Engineer, Delaware Department of Transportation; and Robert Rupert, Highway Engineer, Federal Highway Administration.

Richard A. Cunard, Engineer of Traffic and Operations, Transportation Research Board, assisted the NCHRP Project 20-5 Staff and the Topic Panel.

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

TRAFFIC SIGNAL CONTROL EQUIPMENT: STATE OF THE ART

SUMMARY

Over the past decade, the technological state of the art of traffic signal equipment has advanced drastically. The introduction of microprocessors into the traffic signal industry has greatly enhanced the capabilities of signal control equipment, allowing greater flexibility in signal phasing and timing strategies to better serve traffic. New designs and installation techniques have improved the reliability of vehicular and pedestrian detectors. Signal displays have been refined to require lower maintenance levels and reduced energy consumption yet provide a clear, attention-getting signal indication.

The primary objective of this synthesis is to provide information on the capabilities of currently available traffic signal equipment, including traffic signal controller assemblies, display equipment, detectors, communications for systems, and system masters and other supervisory devices. This synthesis is aimed at new traffic engineers, or practicing engineers who may not have been able to keep up with the latest changes of the state of the art.

One of the elements of the development of this synthesis was a survey of current practice. A questionnaire was distributed to local and state agencies across the United States; the responses received indicate a wide variance in the application and use of the currently available signal equipment. A summary of the responses from this survey is included in Appendix A.

This synthesis includes sections on controller equipment, detectors, systems, displays, and power failure protection equipment. The section on controller equipment includes a discussion of the two predominant types of controllers, the NEMA controller and the Type 170 controller, as well as a description of the functions of conflict monitors, preemptors, loadswitches, flashers, and other similar devices.

Several new detectors are described in the section on detection equipment, as are the refinements being made to inductive-loop detectors, by far the most popular vehicular detector in use. In the section on systems, the wide range of coordination strategies, from time base to central computer, are discussed. Signal displays and their mountings are presented in one section, and new techniques for protecting an intersection during a power outage are discussed in the final section.

CHAPTER ONE

INTRODUCTION

For more than 70 years, electrically operated signals have been used to control vehicular traffic in the United States. The earliest signals were manually operated: Police officers used switches to change the red and green lights. It was not long, however, before simple automatic controllers were developed to relieve police officers of this duty.

Since then, traffic signal control equipment has undergone continual improvement. The earliest signal controllers used motors and gears to time the durations of the signal indications, and direct descendents of these controllers are still in use today. However, the revolution in electronics has brought us to microprocessor-based signal control equipment that is far more powerful and flexible than anything dreamed of just a decade or two ago.

It is this rapid change in the state of the art that prompts the preparation of this synthesis. Practicing traffic engineers, schooled in the signal equipment of the 1950s, 1960s, and 1970s, may not be familiar with the powerful new tools available to help solve traffic congestion problems.

GENERAL REQUIREMENTS OF TRAFFIC SIGNAL CONTROL EQUIPMENT

Traffic signal control equipment, for the purposes of this synthesis, has been defined as including controller assemblies, signal display equipment, detectors, communications equipment, and computerized system equipment. Each of these five categories has seen significant changes and improvements over the past several years, and each will be addressed in detail later in this report.

Primary Considerations

In general, traffic signal control equipment should be designed to achieve three primary goals—safety, efficiency, and maintainability.

Safety is a critical factor in the operation of a signalized intersection. Signal equipment must be capable of operating continuously, as required by the *Manual on Uniform Traffic Control Devices* (MUTCD). Motorists and pedestrians must be provided a clear indication of control so that confusion is avoided. However, even the most reliable equipment can malfunction occasionally; therefore, its design must allow for a "failsafe" operation so that safety problems are minimized.

The second goal, efficiency in operation, has become significant in these days of increasing urban and suburban congestion. Today's traffic conditions require control systems that are responsive to minute-by-minute changes in traffic demands to make the most efficient use of the limited capacities of overcrowded facilities. In addition, by minimizing stops and delays, efficiently operating signals help to reduce air pollution and fuel consumption.

Maintainability is the third goal in the design of signal equipment. Maintenance agencies typically are faced with budgetary constraints, and the number of qualified technicians capable of working on the sophisticated equipment is limited (*1*). As a result, agencies are seeking highly reliable equipment to minimize the number of failures that occur. They are also using equipment with redundant elements to minimize the impact of the failures that still occur occasionally.

Safety, efficiency, and maintainability are enhanced by the addition of features such as the automatic detection and reporting of equipment failures. This feature is now being implemented in many signal systems nationwide. Couple this with equipment that is, by design, easy to maintain (thus minimizing the time and cost to repair and the size of the spare parts inventory), and even a maintenance agency with a very limited budget can carry out its duties in this area effectively.

Additional Considerations

Traffic signal equipment must be capable of standing up to varying environmental conditions. Its roadside location makes it subject to vibrations from passing trucks. In many areas, lightning can be a significant threat to the equipment.

Vandalism is also a concern to today's traffic engineer. Signal heads are frequently shot at, controllers are turned off, detectors are disabled, and controller cabinets are spray painted. Vandal-resistant traffic signal equipment can minimize the threat to public safety caused by vandalism.

Compatibility between various types of traffic signal equipment is an important factor to be considered when selecting equipment. Industry standards and standardized specifications help to ensure a minimum level of compatibility. This in turn allows for less complicated field installation procedures, improved maintenance, and a simpler procurement process.

With the budgetary constraints commonly imposed on traffic engineering agencies, the cost of traffic signal equipment is important. Often, only the cost of procurement and installation is considered by the agency when considering bids. However, the continuing cost of maintenance and operation should also be considered when making a decision regarding the selection of signal equipment.

Finally, the aesthetics of equipment is becoming a more important concern. Too frequently, the goal of reducing "urban clutter" conflicts with the goal of improving signal conspicuity. However, techniques have been found to bridge the gap between these goals and maintain the motorists' respect for the devices.

CHAPTER TWO

TRAFFIC SIGNAL CONTROLLER ASSEMBLIES

A traffic signal controller assembly is defined as "a complete electrical mechanism mounted in a cabinet for controlling the operation of a traffic control signal" (*2*).

There are two primary classes of controller assemblies—the pretimed controller assembly, which provides for the operation of signals with predetermined, fixed cycle lengths, interval durations, and interval sequences; and the traffic-actuated controller assembly, which changes these operations in accordance with the varying demands of traffic, as registered with the controller by vehicle detectors.

The controller assembly comprises at least four key components. The controller unit, the "brain" of the assembly, is devoted to the selection and timing of signal displays. The cabinet is an outdoor enclosure for housing the controller unit and its associated equipment. The input-output facilities provide the interface between the controller unit, the signal display equipment, and the auxiliary equipment in the assembly. The signal monitoring devices prevent the display of conflicting signal indications.

Additional equipment found in the assembly could include: coordination equipment, which provides for an operational relationship with adjacent signalized intersections, and preemption equipment, which allows the controller unit to respond to unusual occurrences, such as the passage of a train or an emergency vehicle. Actuated controller assemblies require additional detection equipment that senses the demands of vehicles and pedestrians approaching the intersection and allows the allocation of variable time intervals for their crossing.

TRAFFIC SIGNAL CONTROLLER UNITS

The controller unit provides the timing and display selection functions for the controller assembly. The controller unit defines the classification of the controller assembly; therefore, there are two primary types of controller units—pretimed and traffic actuated.

Pretimed Controller Units

The earliest automatic controller units were pretimed controllers. These units were relatively easy to construct, using existing electromechanical technology. They consisted of a motor and gear assembly driving an adjustable timing dial. The timing dial provided for the repetitive timing of fixed-duration intervals. A camshaft assembly, advancing for each interval, closed and opened circuits, providing current to the signal indications in the street (*3*).

Over the years, electromechanical pretimed controllers became more sophisticated. By adding circuitry to stop and restart the timing dial in synchronization with a timing pulse on an interconnect cable, the controller could be incorporated into a system to provide progression. Adding timing dials and the circuitry to select between different dials (such as on a time-of-day basis) permitted the use of different cycle lengths and interval durations for critical traffic periods. A common configuration for an electromechanical controller included three dials, which provided a plan for the morning peak period, the evening peak period, and the remainder of the day. In Figure 1, the timing dial and camshaft assembly of a typical electromechanical pretimed controller are shown.

Microprocessor-based pretimed controllers first became popular in the late 1970s. Operationally, they were based on their electromechanical predecessors, using a "signal plan" as a solid-state equivalent to the camshaft assembly, and storing timing data in random access memory. Most expanded on the capabilities of their predecessors, adding such features as multiple signal plans, to change sequences by time of day; minor phase actuation; and internal preemption routines.

Both electromechanical and microprocessor-based pretimed controllers are still widely used, and are available from several manufacturers. They have a number of primary applications, including downtown grid areas, where progression on intersecting streets is desired, and at intersections where unusual sequences can best be accommodated by special signal plans.

One drawback of dedicated pretimed controllers is that there is not an industry-wide interchangeability standard for these devices. Controller units from one manufacturer are not interchangeable with units from another manufacturer. Many jurisdictions are overcoming this limitation by using actuated controller equipment to simulate pretimed control.

Traffic-Actuated Controller Units

Traffic-actuated controllers select phases (the right-of-way, change, and clearance intervals assigned to any independent movement of traffic) and extend phase durations based upon current traffic demands (*4*). Phases without demand can be omitted from the signal sequence; phases with minimal demand are provided only enough green time to satisfy that demand, whereas phases with heavy traffic flows are extended to accommodate the additional vehicles using that phase.

Operation of Actuated Controllers

Actuated controller operations normally range from two phases (typically the alternating of right-of-way between two intersecting streets) to eight phases (which provides for full control of all through and left-turn movements for a "cross"-type

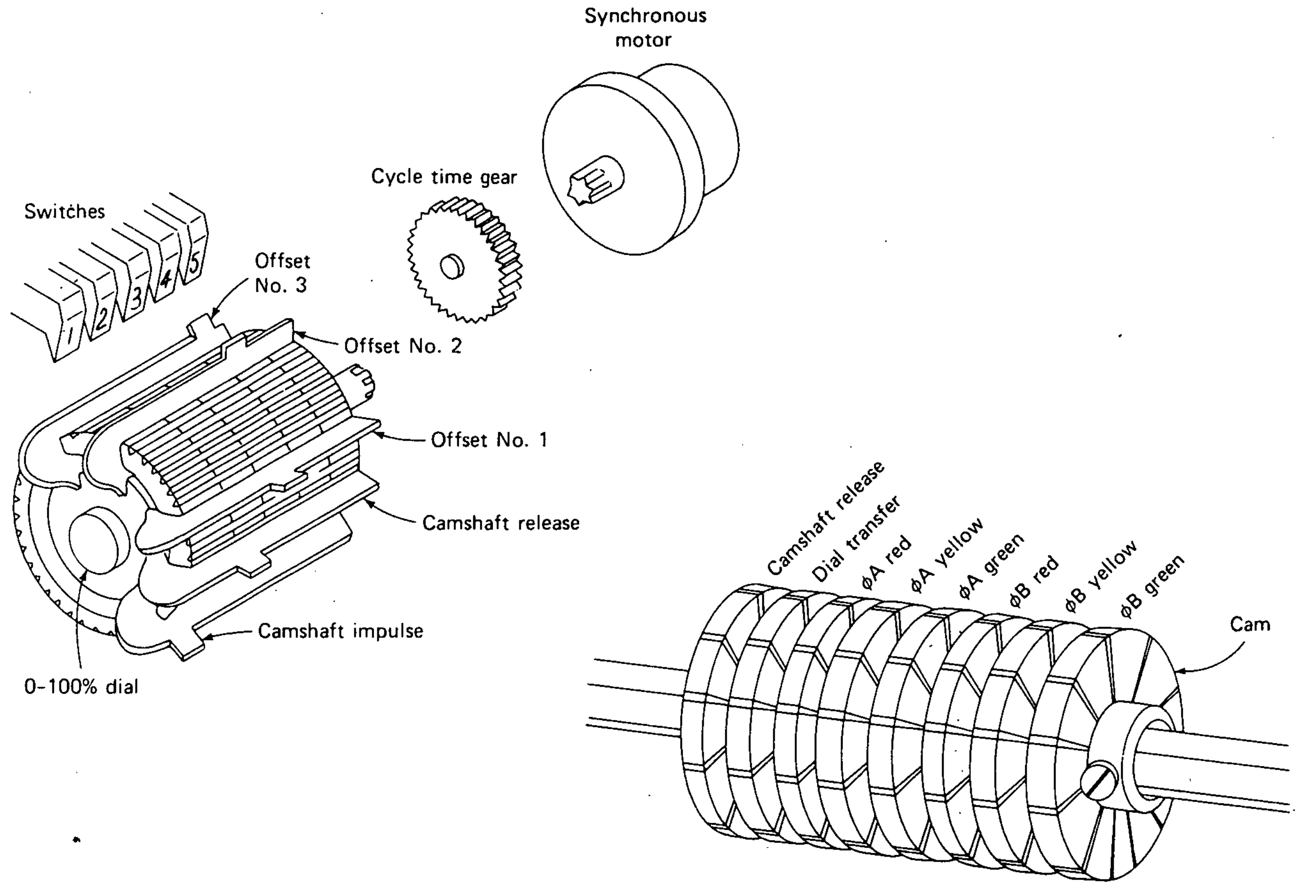


FIGURE 1 Pretimed controller dial unit and camshaft.

intersection). Some controllers may be capable of providing additional phases for unusual intersection operations.

All actuated-controller units made today permit either full-actuated operation (where detector input is received for all phases) or semi-actuated operation (where input is received only for some phases—typically only the side-street or minor movements).

In semi-actuated operation, the controller is configured to rest, or dwell, in the major street movement, free to service side-street demands after timing a minimum green period on the main street. Semi-actuated operation is also frequently used to incorporate actuated controllers into a coordinated system, as the controller can be held in the major street "coordinated" phase based on system-timing parameters, servicing the side street once per background cycle.

Full-actuated operation is often used where demands on both intersecting streets fluctuate throughout the day. The operation also allows the controller unit to recognize the passage of a platoon of vehicles on the major street, holding the green until a gap is detected before servicing the side street.

Phase Operations Most of the controller's timing functions take place on the individual phase level. In basic actuated operation, green time for vehicular movements is based on three independent timing parameters: minimum green, which is provided for a phase with minimal demand; passage (or extension), which extends the green for each additional vehicle actuation; and maximum green, which limits the length of time that the green can be extended when traffic detector input is present for conflicting phases. The relationship of these three parameters is shown in Figure 2.

Many agencies use an enhanced actuated operation, called volume-density control, particularly at higher-speed intersections. Volume-density control permits the placement of detectors well upstream of the intersection without the resultant loss of efficiency in gap detection that would occur in basic operation.

Volume-density adds two features to the timing of the green interval. The added initial feature (Figure 3) allows the controller to extend the minimum length of the green interval based on the number of vehicles that arrived on that approach during the red interval. Gap reduction (Figure 4) permits the gradual decrease of the allowable gap between actuations on the phase timing the green interval, based on the time spent waiting by a vehicle arriving on a conflicting approach.

Pedestrian features of actuated controllers allow for the timing of a WALK and pedestrian clearance (flashing DON'T WALK) interval that, when operating concurrently with a vehicular movement, extends the phase time to provide for a safe crossing. One significant advantage of this operation is that, in the absence of pedestrian demand, vehicular phase time can be kept to a minimum.

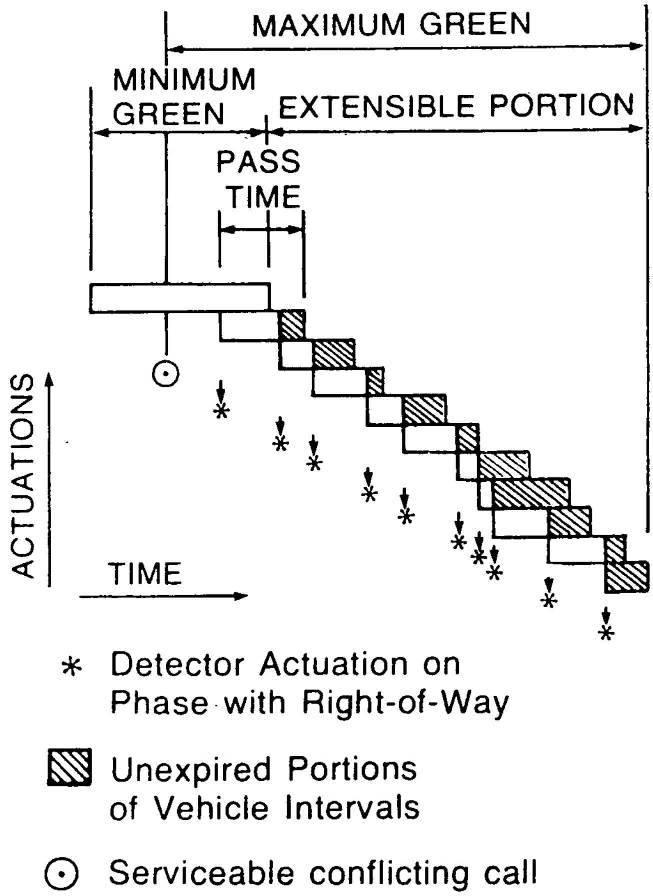


FIGURE 2 Basic timing of actuated green.

When each phase is terminated, the green display is followed by a yellow change interval and, in many cases, a red clearance interval, before the next phase begins its timing.

The Ring Concept The term "ring" is defined as two or more sequentially timed and individually selected conflicting phases, arranged to occur in an established order (*5*). Most actuated controllers operate as either a "single-ring" or a "dual-ring" controller, although some controllers allow additional rings to be defined.

The basic two-phase controller operation is probably the most common single-ring sequence. Phase 1, typically the major street, is followed in sequence by phase 2, the side street. Figure 5 illustrates several common single-ring configurations. The sequence that the controller follows in selecting phases, when demand exists on all phases, is called the "preferred sequence."

Dual-ring controllers contain two interlocked rings, and allow the concurrent timing of phases in both rings. A dual-ring controller can be best illustrated in an eight-phase, "quad-left" operation, as shown in Figure 6. The preferred sequence of the quad-left operation is, in ring 1, phases 1, 2, 3, 4, and back to 1 and, concurrently in ring 2, phases 5, 6, 7, 8, and back to 5. There are some constraints on the concurrent timing, represented by the "barrier" in the figure; only one phase from each ring to the left of the barrier, or to the right of the barrier, can time concurrently.

Proceeding through the dual-ring controller sequence, and assuming some level of demand on all phases, the controller sequence starts with the timing of concurrent, opposing left turns on one of the roadways, as shown in Figure 7. If the demand for phase 1 is less than the demand for phase 5, phase 1 will terminate and phase 2 will begin timing concurrently with the still-timing phase 5. When phase 5 eventually terminates, either because of the satisfaction of demand or the expiration of the maximum green timer, phase 6 will start timing concurrently with the already-timing phase 2.

It would be a conflict if, for example, phase 2 terminated early and crossed the barrier to begin timing phase 3 while phase 6 was still timing. Therefore, when the controller crosses the barrier, phases in both rings must terminate concurrently; i.e., phases 2 and 6 time their yellow and red clearance intervals together, then phases 3 and 7 start their timing together.

The operation to the right of the barrier is identical to that on the left of the barrier. Phases 3 and 7 can terminate independently of each other, and advance to the next phase in sequence. However, when phases 4 or 8 terminate, the barrier must be

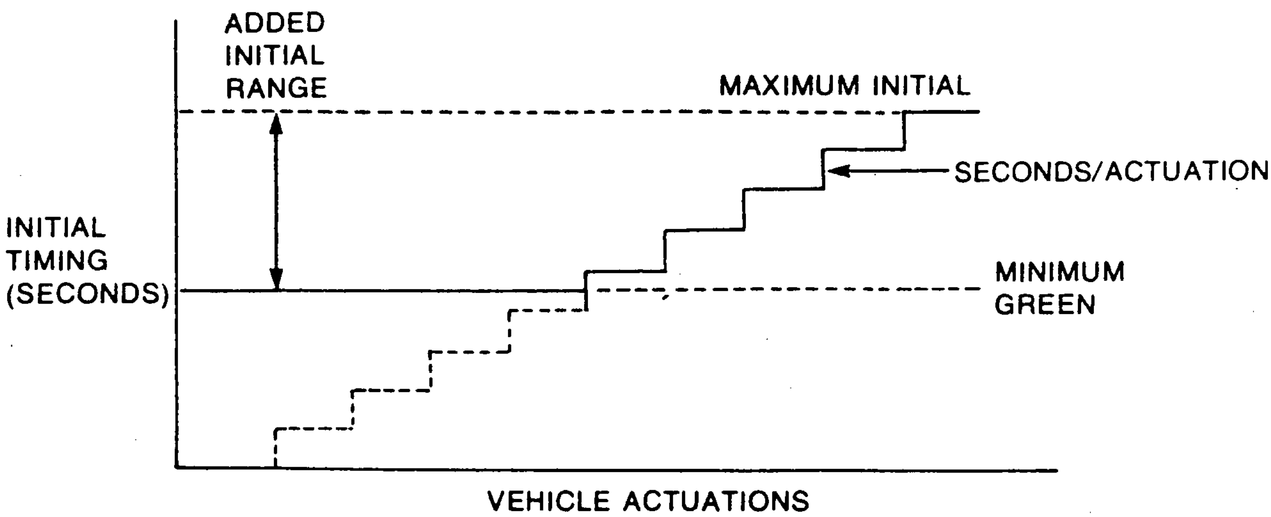
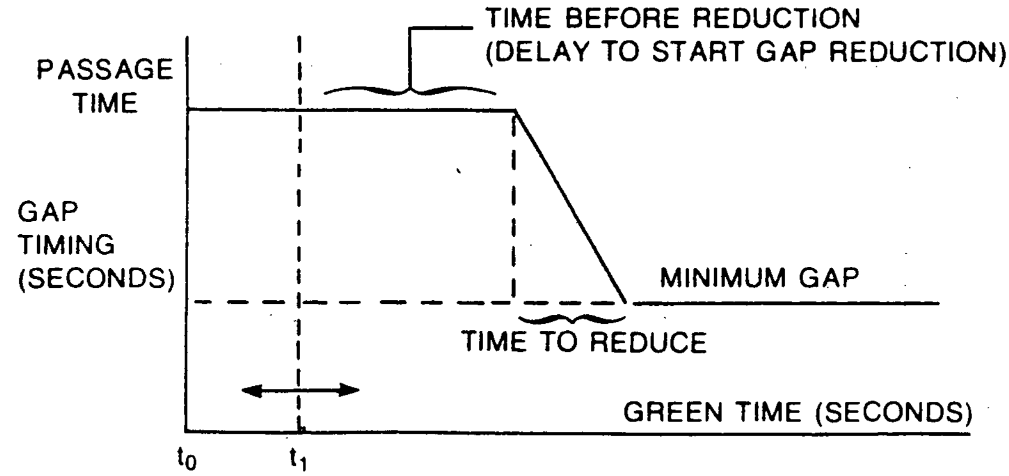


FIGURE 3 Timing of added initial function.



(a) t_0 = Start of phase GREEN.
(b) t_1 = Registration of serviceable conflicting call.
(c) TIME BEFORE REDUCTION shall not start timing before t_0.
(d) MAXIMUM timer start shall be conditional upon being in the GREEN interval and registration of a serviceable conflicting call—vehicle or pedestrian.
(e) PASSAGE TIME portion of GREEN interval *must* time concurrently with INITIAL subject to vehicle actuations.

FIGURE 4 Timing of gap-reduction function.

crossed, and both phases must terminate concurrently before advancing to phases 1 and 5.

Other intersection signal operations can be accommodated within the standard dual-ring configuration, as shown in Figure 8. Many controllers permit variation of the standard dual-ring sequence, to provide even greater flexibility in operation.

Operator Interface Virtually all of today's actuated controllers are microprocessor-based and store user-entered timing values in memory. The calculator type of keyboard has become the most popular means of data entry, with various levels of machine prompting for user responses [e.g., liquid crystal or LED (light-emitting diode) displays].

Downloading of controller parameters from a central data base system is becoming a popular option, particularly with the proliferation of personal microcomputers and the recent popularity of laptop microcomputers. Controller parameters, including multiple coordination patterns and complex preemption routines, can be entered, in the relative tranquillity of the office or shop, into a microcomputer and transported to the field for downloading into the controller. Some controllers provide an easily removed and replaced "personality chip," a memory device that contains all controller timing and configuration parameters related to a specific intersection, allowing the quick replacement of controller units at an intersection. Finally, more and more systems will have the capability of downloading data directly to the controller over the communications interconnect lines.

The National Electrical Manufacturers Association Standards

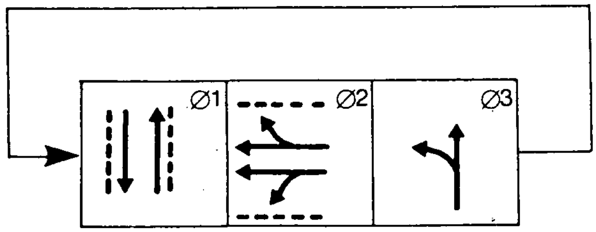
The National Electrical Manufacturers Association (NEMA) is an organization of manufacturers of various types of electrical equipment (*2*). One of the association's primary functions is the development of standards that define a product, process, or procedure relating to electrical equipment.

In 1976, NEMA's traffic control equipment subdivision published its first standards document, which covered operational and interface standards and environmental requirements for actuated controller units and solid-state load switches, as Standard TS1-1976. Since that time, the organization has expanded the standard (now identified as TS1-1983) to include inductive loop detectors, conflict monitors, solid-state flashers, terminal facilities, and an updated "advanced" actuated-controller unit.

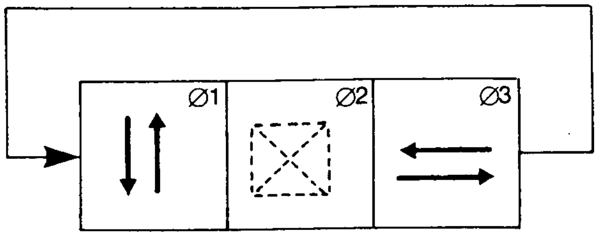
In the NEMA standards, the actuated-controller unit (Figure 9) is defined to be interchangeable with actuated units from other participating manufacturers, in terms of function and electrical connector interface. The standards do not define how the manufacturers build their controller unit—in fact, a microprocessor-based design is not mentioned in the standards, although virtually all currently available machines are based on microprocessors—as long as the unit functions in conformance with the operational requirements of the standards and is electrically interchangeable with other similar units.

Most manufacturers of NEMA-actuated controllers offer controller functions beyond those defined in the standards. These "beyond NEMA" functions include preemption, time-based coordination, hardwire coordination, and special phasing sequences. Previously, these functions were accomplished through auxiliary logic devices external to the controller unit; however, the power of the microprocessor allows these to be performed internal to the controller with a much higher level of reliability, for much less initial and ongoing cost.

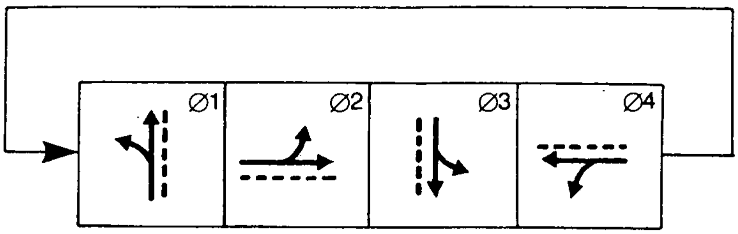
One drawback of the "beyond NEMA" functions has been the lack of a standardized connector to access these functions within the controller unit. Each manufacturer has designed its own connector configuration, so that controller units from different manufacturers will not be interchangeable if these functions are required for operation. Some agencies require that an interface cable be supplied for all features to be mated to a defined connector in the cabinet. Many agencies, however, are finding this not to be a significant problem, as a spare controller unit typically is less expensive than the added auxiliary equipment necessary to perform the functions externally.



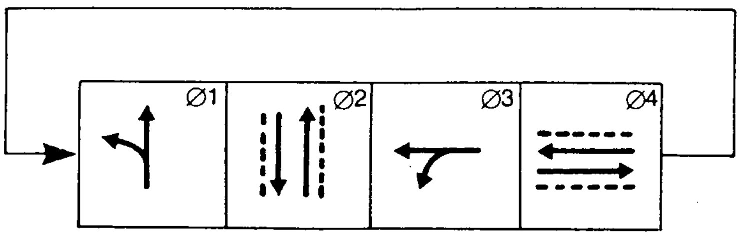
Intersection with one-way street, leading left turn



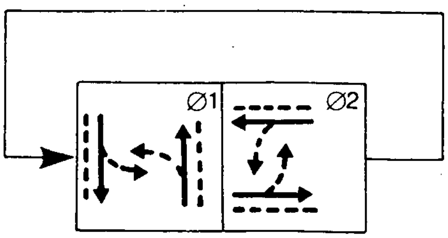
Intersection with exclusive pedestrian phase



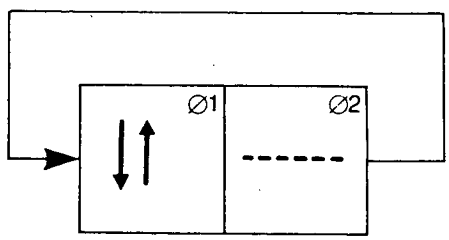
Sequential approach phasing



Leading lefts in two directions
(Should not be used where opposing
left turn phases are anticipated)



Standard + intersection



Midblock crosswalk

FIGURE 5 Examples of single-ring operations.

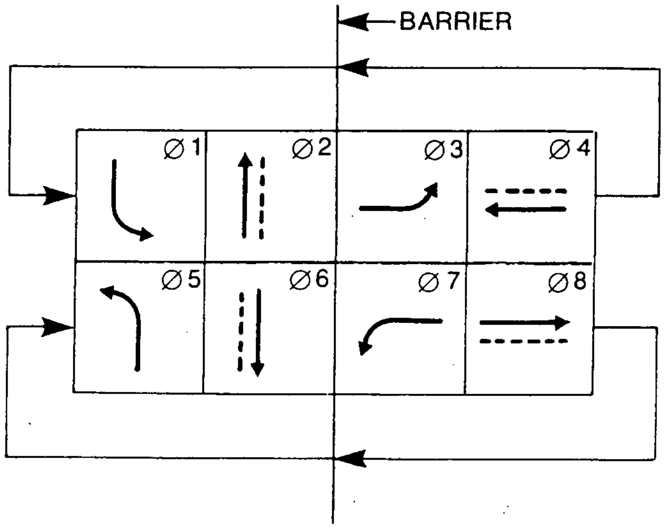


FIGURE 6 Eight-phase "quad-left" operation.

National Electrical Manufacturers Association members are currently working on a new standards document, dubbed "TS2," which will define a greatly enhanced actuated controller unit. This unit will include provisions for standardizing special functions not currently addressed by the NEMA standards.

The Type 170 Controller

Almost concurrently with the development of the NEMA standards in the mid 1970s, the states of California and New York teamed in the development of specifications for a traffic controller assembly centered around the Type 170 controller unit. These specifications include requirements for the controller unit, cabinets, detectors, load switches and flashers, conflict monitor, and internal modem (*6*).

The Type 170 controller unit (Figure 10) is defined as a "general purpose" microprocessor controller, with the specifications calling out such features as the type of microprocessor, memory requirements, physical dimensions of the unit, keyboard and display layout, connector configuration, and environmental requirements. However, the hardware specifications do not include the functional requirements that would make the unit an operating traffic signal controller.

The controller unit is designed to accept a removable memory module containing software that defines the function of the controller. By writing and installing different software packages, agencies have operated the controller unit as an actuated controller, ramp metering controller, pretimed controller, arterial master, or detector processing station.

It was anticipated by the unit's designers that the functions previously performed externally to a controller unit—such as preemption and hardwired coordination—could be accomplished internally through software. In many instances, new features have been added to an existing controller unit simply by replacing the software package.

However, software development is not an easy task, and has typically been left to experienced programmers at the larger agencies or at one of several systems software consultants. Most new software development consists of enhancements to existing intersection programs, adding features such as systems communications or other specialized functions.

The hardware specifications have been modified over the years to reflect changing technologies. Advances in available memory capabilities have been accommodated by revisions to the removable memory module, as has the addition of a more accurate clock to provide for time-based coordination.

New York State has developed specifications for an updated controller unit, identified as the Type 179. Using a newer, more powerful microprocessor, additional memory, and enhanced display, the controller provides a new starting point for added system capabilities. The Type 179 cannot directly run software developed for the Type 170. However, the Type 179 does have identical input-output facilities as the Type 170, so that it can

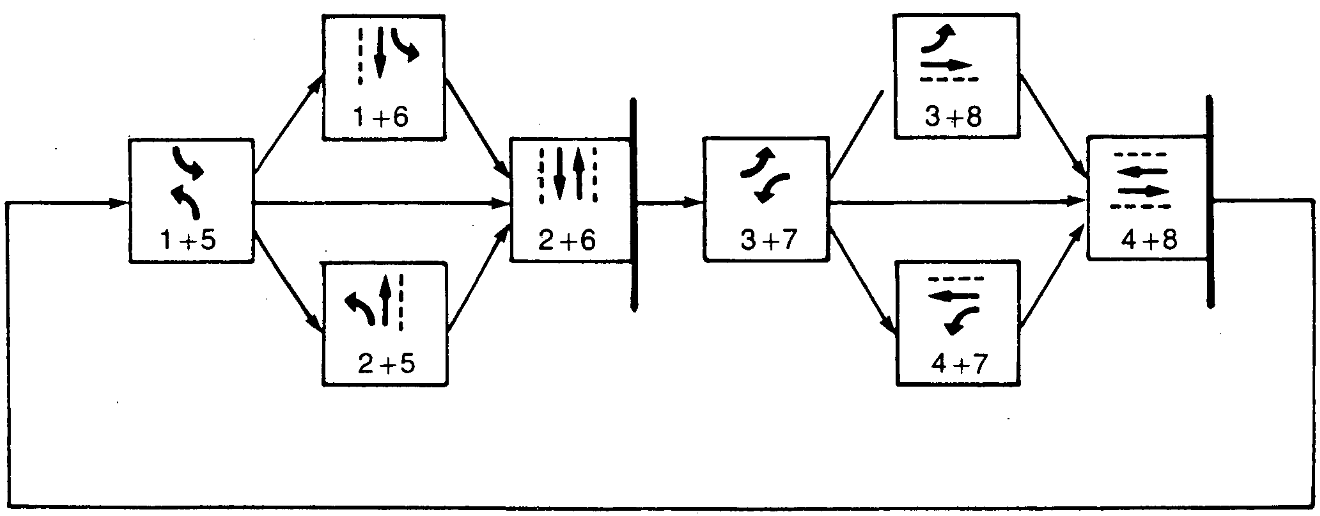


FIGURE 7 Phase combinations in eight-phase operation.

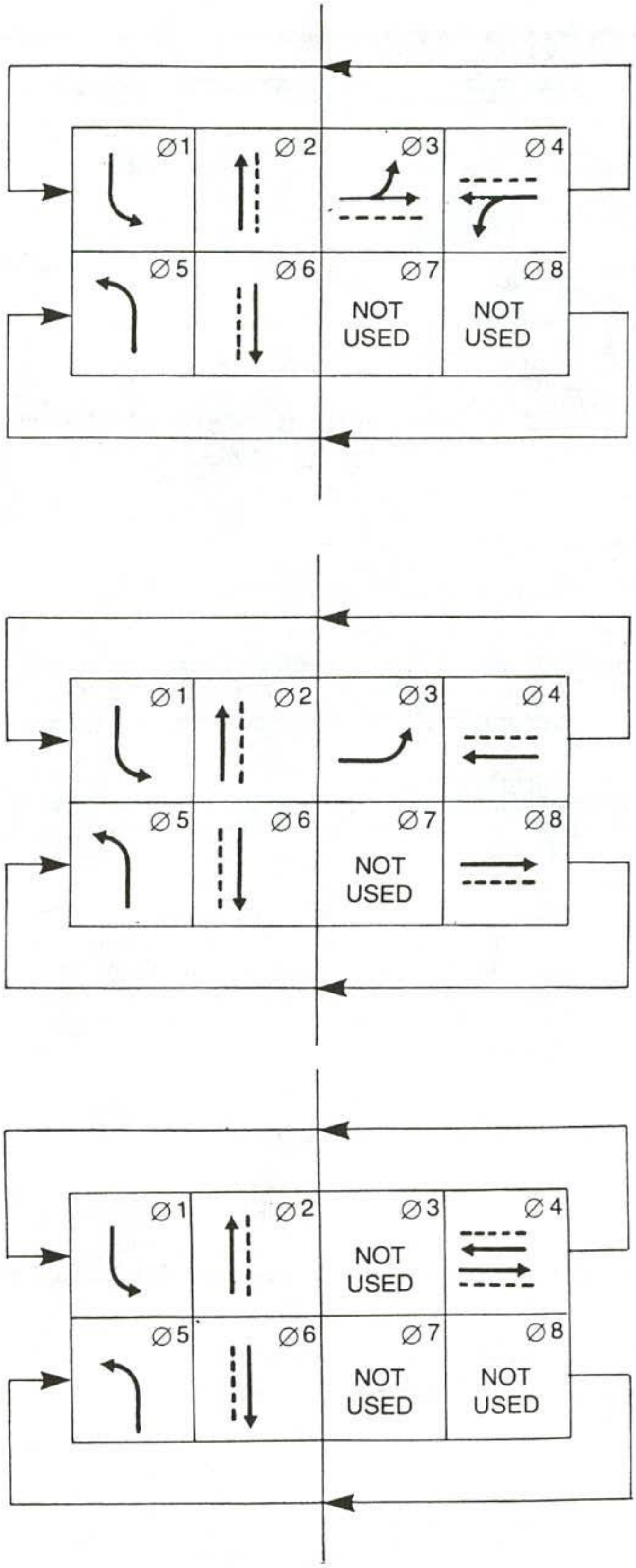


FIGURE 8 Examples of dual-ring operations.

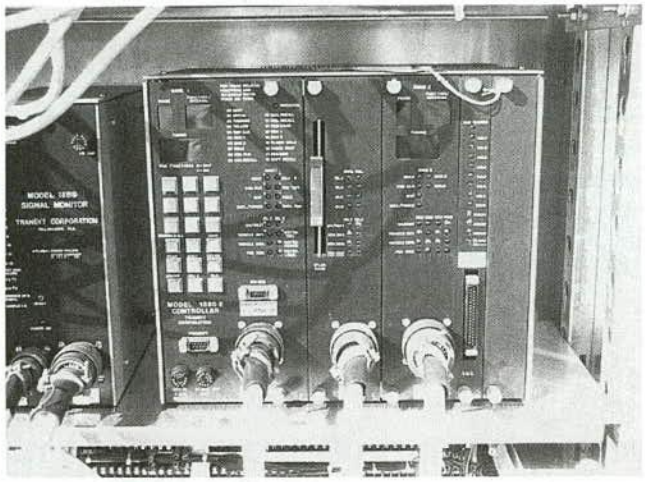


FIGURE 9 Typical NEMA controller unit.

be used in the same cabinets, with the same auxiliary equipment, to prevent the obsolescence of the older equipment.

CONTROLLER MONITORING EQUIPMENT

One of the few disadvantages of the technological advancement from electromechanical signal control equipment to solid-state equipment is that the potential for the accidental display of erroneous indications in the street increased.

Although controller units themselves sometimes cause problems, the primary culprit is the solid-state load switch, which acts on the low-voltage outputs of the controller unit to switch on and off the electrical current to the lamps in the signal heads. The switching modules, when they fail, typically fail in the conducting or "on" mode. Should a module for one phase's green indication fail "on" when a conflicting phase is timing a green, a potentially dangerous display of conflicting indications would be shown in the street.

To protect against this condition, the conflict monitor was developed. Early models protected only against green indications on conflicting movements; current models provide a host of extended functions. When any trouble is detected by the monitor, the intersection is automatically transferred to the failsafe flashing mode, and the controller is held in its current state by a "stop timing" input command.

Solid-state controller equipment should never be operated without the monitor in place and operating. A regularly tested monitor is considered by many to be "cheap insurance" against claims of conflicting indications. In a survey conducted for this synthesis, all respondents indicated that conflict monitors are required for new controller assemblies.

Monitoring Capabilities

The two primary types of conflict monitors—those for use with NEMA controller equipment and those used in the Type 170 family of controllers—have similar, but not identical, functional capabilities. Both types of monitors have basic functions that are defined in their respective standards or specifications,

TYPICAL TYPE 170 CONTROLLER

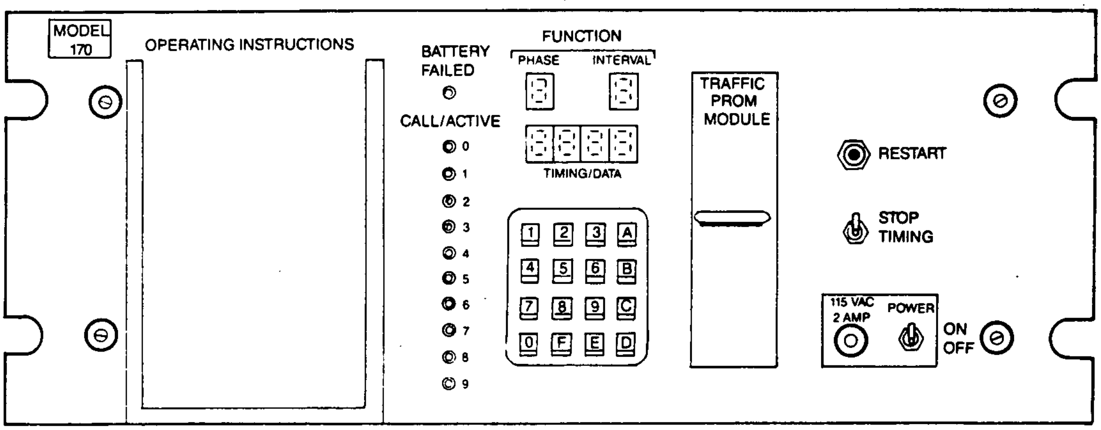


FIGURE 10 Type 170 controller unit.

and also have optional features offered by the various manufacturers. Commonly found functions are described in the following sections.

Channel-to-Channel Conflict Detection

Both types of monitors protect against the display of greens, yellows, or WALKs on conflicting movements. To define which movements are conflicting, the monitors assign a channel to each movement; the monitor can then be programmed to identify which combinations of channels can safely be displayed in the field. Upon sensing any other combinations, the monitor will place the intersection into flash.

National Electrical Manufacturers Association standards define a channel as four 120-volt AC inputs to the monitor—the green, yellow, red, and WALK loadswitch outputs for any one movement (phase or overlap). The Type 170 specifications for the Model 210 monitor define a channel as two 120-volt AC monitor inputs, for each movement's green and yellow loadswitch outputs. In the Model 210, a movement's WALK indication is monitored as a separate channel.

Both types of monitors sense the presence of voltages on the inputs to determine if a conflict exists. Should two noncompatible channels have voltages at a level sufficient to even dimly illuminate a signal lamp for a duration exceeding half a second, the monitor will trigger and place the intersection into flash. This will protect not only against the failure of a load switch or a controller unit, but also against a short circuit in field wiring, where a permissive indication's circuit could be energized erroneously by electrical contact with any other active circuit.

"Absence of Red" Monitoring

Standard on NEMA monitors, and available as an option from the manufacturers of Type 170 monitors, is the "absence of red" monitor function. The term is really a misnomer, because the monitor is actually checking for the absence of a display output on any one channel by monitoring the voltages on each channel's inputs.

The function's logic is that if green is not on, and yellow is not on, then red should be on. If not, a problem is assumed, and the intersection is placed into the flashing mode. Note that this function is triggered by the absence of voltage on any input (green, yellow, or red) to the channel, not just the red.

It should be emphasized that this feature does not protect against the absence of a red indication on a movement caused by burned-out bulbs or broken signal wiring. The monitor is checking for a voltage output from the load switches, and is not determining if current is being drawn on the circuit—the only way to determine if bulbs are being illuminated.

Controller Unit Voltage and Line Voltage Monitoring

Conflict monitors can also check for proper voltage levels within the cabinet and controller unit. Both controller systems use a 24-volt DC power supply (internal to the NEMA controller, and a separate, external supply for the Type 170) to operate auxiliary devices such as load switches and detector inputs. The monitors can observe these voltage levels and, if the levels fall below a specified threshold, place the intersection into flash until appropriate voltage levels are resumed.

The NEMA controller unit performs some voltage monitoring internally, and generates an output that is active when conditions are within tolerances. This output, the controller voltage monitor, also is typically tied to the watchdog monitor described below.

The conflict monitor also monitors itself for proper supply voltages; in case of a brown-out, or failure of the monitor's power source, the intersection will be placed into flash until the condition is corrected.

Controller Watchdog Monitoring

Microprocessor-based controller equipment may occasionally experience a "stall" condition, in which the microprocessor loses track of its place in the program and stops. This is usually in response to electrical interference (nearby lightning is a primary cause) or, rarely, to a software error.

To protect against this, controller hardware and software designers use a "watchdog timer" circuit. The running program resets a memory address at regular intervals, typically about 10 times a second. A hardware timer circuit observes this memory address, and if the proper resetting is not occurring, the watchdog identifies an error condition.

In Type 170 controllers, the watchdog circuit is part of the conflict monitor itself. In NEMA controllers, the watchdog is internal to the controller unit, with the watchdog output usually part of the controller's voltage monitor circuit logic. In either case, a microprocessor stall will cause the intersection to go into flashing operation.

Intrachannel Conflicts

Monitors conforming solely to NEMA standards or Type 170 specifications check only for conflicts between noncompatible channels; they do not check for intrachannel conflict conditions, such as green-yellow, green-red, and yellow-red combinations within the same signal face. These combinations appear when an electrical short occurs between the green and yellow outputs, or when a red load switch module fails "on." They are not conflicts with other movements, but can be confusing to motorists observing the indications.

Most manufacturers offer conflict monitors with optional features to protect against some or all of these intrachannel combinations; these features are in addition to the requirements of the appropriate standards or specifications. Many agencies are opting for this added protection.

Short-Yellow Monitoring

Several manufacturers of conflict monitors are also offering an optional feature that protects against skipping or displaying a too-short yellow interval. This function requires that a minimum yellow (2.5 to 3.0 sec) be displayed in every change from a green to a red on a channel.

The current NEMA standards call for a controller unit to be capable of timing a yellow interval ranging from 0 to 7 sec. However, most controller manufacturers provide a software minimum timing feature of 3 sec. The conflict monitor short-yellow function is added protection for these controllers, but has added significance for those controllers without the 3-sec minimum interval duration.

Burned-out-Bulb Protection

As mentioned earlier in the absence of red discussion, the standard conflict monitor does not protect against the lack of an indication caused by burned-out red bulbs. Neither will it directly protect against burned-out yellow or green indications—the monitor only observes voltage levels and not current draw, which is an indicator of circuit completion through a bulb filament.

However, the standard monitor will trigger and indicate a channel-to-channel conflict error message if all yellow, green, or WALK bulbs on a channel burn out. This is caused by a quirk in the design of solid-state load switches, and is frequently a problem where single display heads are used, such as on a left-turn phase display. Many agencies require a loading resistor to be installed on all single-display greens to avoid placing the intersection into flash for this noncritical condition.

Event Logging/Diagnostic Displays

As an aid to the maintenance person troubleshooting an intersection in conflict flash, some monitors provide additional displays for diagnostic purposes. Such displays can include the current state of all monitor inputs (not just active channels), and the logging, by date, time, and error type, of recent events (power failures, conflicts, etc.) identified by the monitor.

Current Monitors for Burned-out Bulbs

The New York State Department of Transportation has developed a specification for a current monitor to protect against continued operation with burned-out bulbs. The monitor, which is a separate assembly included in their Type 179 controller's cabinet, monitors the current flowing through the supply feed to each load switch. The absence of current indicates that an output is not being displayed in the street.

The unit's minimum dimensions are constrained by the size of the current-sensing modules. It does, however, help to protect against burned-out indications, and to generate a warning message if the controller is included in a computer-based signal system.

A couple of manufacturers are also offering bulb-failure protection, based on the sudden drop in overall display current when a bulb filament fails. Activation of this device can be used to send a maintenance message to a central computer, or place the intersection into flash.

There is some debate over whether an intersection should be placed into flash because of a bulb failure. Most engineers feel that it is unnecessary for the loss of one lamp, or the loss of all greens on an approach. The loss of all yellows or all reds on an approach presents a hazardous condition, yet flashing the intersection may still not provide an indication to the dark approach.

The Malfunction Management System

The Malfunction Management System concept was developed as part of a Federal Highway Administration (FHWA) research project. The intent of the concept was to incorporate malfunction identification and correction techniques into existing microprocessor-based intersection controller equipment. Included in the functional specifications developed as part of the project were cabinet facility monitoring and redundancy in features (*7*).

INPUT/OUTPUT FACILITIES

Today's microprocessor-based traffic signal controller units do not have the capability to internally switch the electrical current outputs necessary to operate the traffic signal bulbs on the street. In addition, many inputs to the controller unit, including system interconnect, preemption devices, and detectors, must first pass through protective interface devices to isolate the controller unit from the surrounding electrical environment.

The type of controller assembly—NEMA or Type 170—dictates the type of facilities that will be used. The NEMA controller unit, as well as its auxiliary equipment, is designed to connect, via cable harnesses, to a terminal facility in the cabinet, known as a backpanel. The Type 170 cabinet system includes a rack-mounted combination of interface chassis, called the input and output files, which use card-type plug-in component designs for detectors, preemption devices, and the conflict monitor.

Output Devices

Output devices provide for a means of controlling the 120-volt AC currents necessary to drive the lamps in the signal heads at the intersection. The NEMA-style backpanel and the Type 170's output file perform a similar function by providing sockets for three-circuit, solid-state relay packages called "load switches" in NEMA terminology and "switch packs" in the Type 170 specifications. These relay packages act on the 24-volt DC outputs from the controller unit to switch on and off the power to signal displays.

Both systems must also have a flasher, to provide flashing power when the intersection operates in the flashing mode. Flashers are very similar in design to load switches, using a plug-in design for easy replacement.

To switch between the loadswitch outputs, for stop-and-go operation, and the flasher outputs, for flashing operation, a series of heavy-duty flash-transfer relays are necessary, and are also found as part of the output facilities of each controller assembly.

Input Devices

Devices generating inputs into the controller unit include detectors for both vehicles and pedestrians; system interconnect and coordination devices; and preemption equipment, all of which are common to both the NEMA and Type 170 controller approaches and which are discussed in more detail in later sections.

One component unique to the Type 170 system is the "isolator." Used to provide an isolated electrical circuit for input into the controller unit, the isolator is a plug-in module used for pedestrian push-button circuits, some preemption inputs, and hardwire multiconductor interconnect systems.

CABINETS

Controller cabinets are outdoor enclosures designed to house the controller unit and its associated equipment. Cabinets provide for the security of, and the environmental protection of, the signal control equipment. The cabinet also serves to protect the curious from potentially dangerous electrical hazards.

Cabinets come in various sizes and can be configured for three primary mounting techniques—base mounted on a concrete foundation, for larger cabinets; side-of-pole mounting, for small to medium-size cabinets; and post top mounting, also for small to medium-size cabinets. Examples are shown in Figure 11.

Modern cabinets are fabricated of either sheet aluminum or sheet steel. Aluminum eliminates the need for painting, unless desired for aesthetics, and provides a weight advantage over steel cabinets. However, aluminum cabinets tend to be more expensive.

Cabinet Design Configurations

The NEMA standards do not address design requirements for cabinets. However, the typical cabinet for a NEMA controller assembly, as shown in Figure 12, is a cabinet with a large front door; one or more internal shelves for the placement of the controller unit, conflict monitor, and detectors; one or more electrical termination panels making up the backpanel assembly; and a small compartment, located behind a small door in the main door, for the location of police control switches.

The Type 170 Specifications include requirements for three intersection controller cabinets—the Model 330, Model 332, and Model 336. All include the standardized rack-mounting system for the various components of the system. The Model 330 cabinet, included in the New York State-generated specifications, is a moderately sized single-door cabinet, capable of being mounted either on a foundation or on the side of a pole.

The Models 332 and 336 cabinets are unique in the traffic-control industry. They have two full-size doors, one on the front of the cabinet and one on the back. The components of the cabinet assembly are configured so that all control functions, indicators, and switches are accessible through the front door, and all field-wiring terminations can easily be accessed through the back door. The Model 332 cabinet, shown in Figure 13, is tall, and can only be mounted on a foundation. The Model 336 is a shorter version, and can be mounted either on a foundation (with a short sheet metal pedestal adapter) or mounted on the side of a pole.

Controller Cabinet Location and Aesthetics

The appearance of the cabinet, particularly in urban and suburban areas, is becoming a concern to adjacent property owners and others interested in urban aesthetics. Unfortunately, the size of the cabinet for a modern controller is significantly larger than the cabinets used on the older electromechanical pretimed controllers common to downtown areas.

The location of the cabinet plays a big role in the aesthetics of the cabinet—if the cabinet can be hidden from view, then it is not unattractive. However, this is a difficult task in most urban areas. Some agencies have tried to locate cabinets in underground vaults, or in utility rooms of adjacent buildings. However, this usually limits the accessibility to the controller by maintenance personnel, and also restricts the view of signal indications from the cabinet location. Wherever it is installed, care should be taken to ensure that it does not present a hazard to pedestrians.

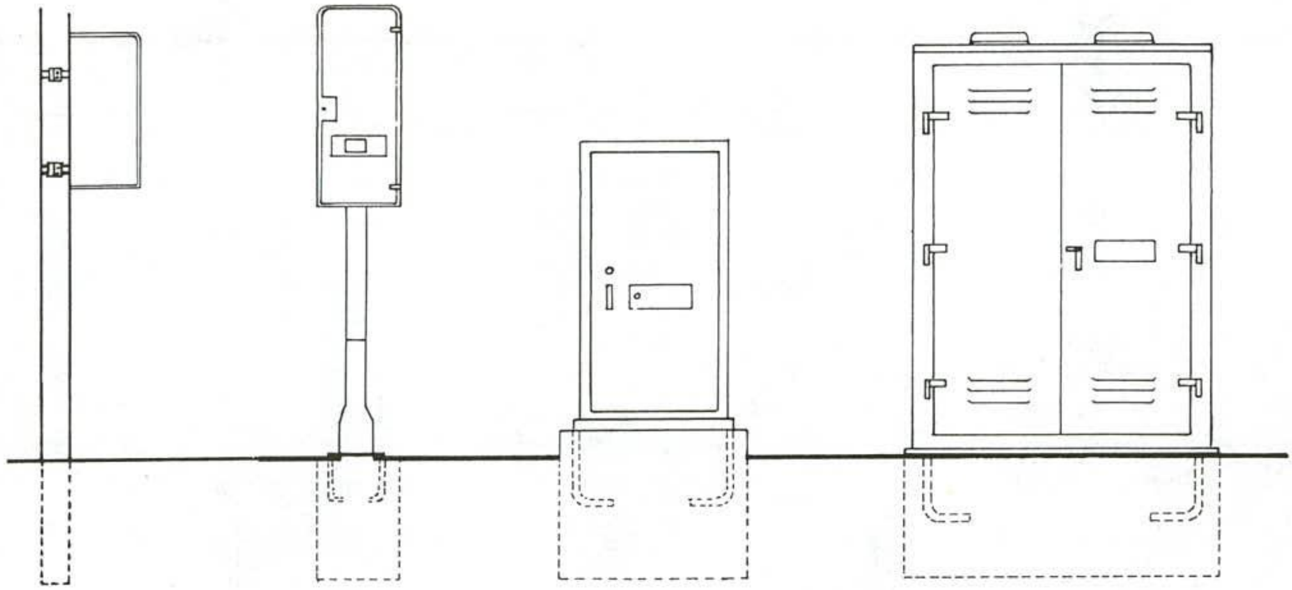


FIGURE 11 Cabinet mounting alternatives.

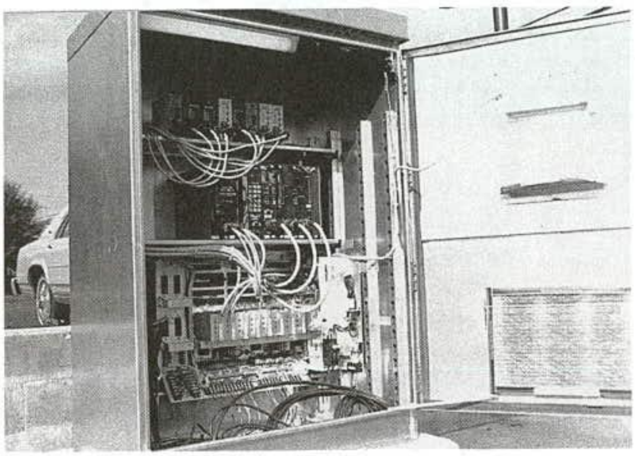


FIGURE 12 Typical NEMA controller cabinet.

Cabinet finishes can also affect the aesthetics of the installation. Natural (unpainted) aluminum cabinets provide a clean, utilitarian appearance and are maintenance free. Scratches will weather out of the finish, and posters and spray paint grafitti can easily be removed.

A painted cabinet may provide a better appearance, if the paint can be well maintained. However, colors should be light, because dark colors will increase the internal temperature of the cabinet significantly, possibly resulting in damage to the electronic equipment housed within.

Incorporation into "street furniture" (design-coordinated street lighting and traffic signal supports, bus stop benches, trash receptacles, and so on) in urban areas can help, and in suburban areas, landscaping around the cabinet can be a big improvement to an installation in an aesthetically sensitive area.

COORDINATION EQUIPMENT

The coordination of signalized intersections is often an effective means of improving traffic flow along an arterial or through a grid network. When signals are coordinated, they operate within a preestablished relationship to minimize stops and delays to the predominant flows of traffic.

Current signal controllers can easily be implemented into a coordinated system. With today's microprocessor-based controller equipment, coordination routines can be included in the controller software, and system integration requires little, if any, hardware modification.

Today's systems range from simple, time-of-day systems, using either time-based or hard-wired techniques; through traffic-responsive arterial system control, such as can be provided by the distributed master, or "closed loop" systems; to the large-scale central computer systems, such as the Urban Traffic Control System (UTCS). Chapter 4 of this synthesis details the current standing of the various system technologies available to the traffic engineer.

PREEMPTION

Preemption is the modification of a traffic signal's normal operation to accommodate an unusual occurrence, such as the approach of an emergency vehicle, the passage of a train through a grade crossing, or the opening of a drawbridge. For these cases, the preemption routines are used to enhance the safety of the intersection and, in some cases, to minimize the effects to traffic caused by the unusual occurrence. Another form of preemption can also be used to provide priority to transit vehicles, to minimize delays to these high-occupancy vehicles.

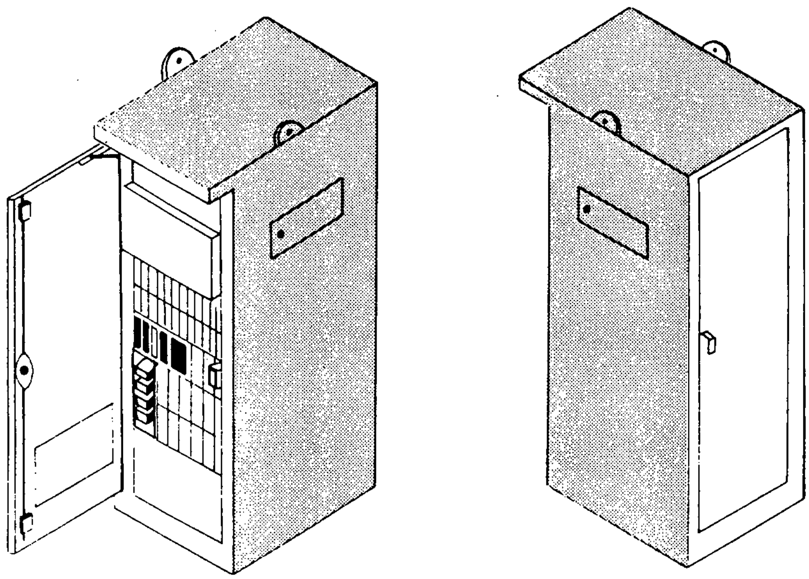


FIGURE 13 Model 332 cabinet for Type 170 controller.

Applications for Signal Preemption

As mentioned previously, preemption can be used to accommodate unusual occurrences at or near a signalized intersection. Primary applications include signals adjacent to grade crossings; signals in front of a firehouse or along an emergency vehicle's normal route, activated by personnel at the firehouse; signals that can be preempted by moving emergency vehicles and are not tied to a fixed route; signals near drawbridges; and signals along a transit vehicle's route.

Railroad Crossing Preemption

The preemption of signal operations caused by the passage of a train is probably the most common use of preemption equipment. Where a signalized intersection is adjacent to a railroad grade crossing, preemption should be used to eliminate the potential for conflicting instructions from the railroad crossing signals and intersection signals. The MUTCD describes several preemption strategies and defines the requirements for grade-crossing preemption.

Railroad preemption requires interconnection between the traffic signal controller and the grade-crossing signal equipment. The preemption routine at the traffic signal controller is initiated by the approach of a train, as detected by the railroad's controller, and typically starts with a short "track clearance" phase, to clear motorists who may be stopped between the railroad crossing stop bar and the intersection.

Subsequent signal displays include only those that would not be conflicting with the occupied grade crossing. When the train has passed, the preemption sequence is typically designed to provide right-of-way priority to vehicles that have been stopped by the preemption sequence, then return to normal signal operations.

Firehouse/Fire Route Preemption

There are several forms of firehouse or fire route preemption; the common denominator for this category is the activation of the preemption sequence at some fixed point, typically a push button located within the firehouse. Of course, this operation is not limited to fire department vehicles; the technique is appropriate for any emergency-response vehicle.

The simplest form of firehouse preemption is the installation of an "emergency signal," typically at the firehouse driveway's intersection with a major through street. Using essentially a two-phase semi-actuated controller, the signal dwells in the through-street display (green or flashing yellow) until called by an actuation in the firehouse. The signal then provides a timed right-of-way to the driveway, to allow emergency vehicles to enter or cross the major street.

Where the firehouse is near a signalized intersection, a preemption sequence can be designed to display a special movement permitting the passage of emergency equipment through the intersection.

When emergency vehicles frequently follow the same route through more than one nearby signal, it may be desirable to provide a fire route-preemption operation. Actuation of the firehouse push button will be transmitted to all the signals along the route, and after a variable timed delay, each signal will provide a preempt movement display. This will provide a one-way "green wave" away from the firehouse, allowing the optimal movement of emergency equipment.

Several large computer-based signal systems provide for a computer-generated fire route-preemption sequence, initiated either by the fire department's central dispatcher or by the selection of one of several routes available from each firehouse.

Moving Emergency Vehicle Preemption

A number of devices are available to permit the preemption of signals by moving vehicles. In each case, the preemption equipment causes the signals to advance to a preempt movement display, much the same as the fire route sequence described previously. The differences in the systems are in the techniques of identifying the presence of the approaching emergency vehicle.

One such system uses a light emitter on the emergency vehicle and a photocell receiver for each approach to the intersection. The emitter outputs an intense strobe light flash sequence, coded to distinguish the flash from lightning or other light sources. The receiver electronics package identifies the coded flash and generates an output that causes the controller unit to advance through the desired preempt sequence.

A second type of system uses a low-power radio transmitter on the emergency vehicle and a radio receiver at each intersection to be preempted. The driver of the vehicle activates a dashboard switch based on the heading of the vehicle—north and south or east and west. This switch codes the radio transmission, and the intersection receiver can implement the appropriate preempt sequence. One recently introduced system using this technique includes a compass-based switch in the emergency vehicle and encodes the vehicle's identification number for preemption logging purposes.

Both of these systems require a specialized transmitting device on each vehicle for which preemption is desired, and require that drivers activate the transmitters during their run and turn off the transmitters after arriving at the fire scene.

A third system uses a receiver at the intersection that senses the emergency vehicle's siren to initiate preemption. This system cannot provide directionality of approach; however, it can be used to start a predetermined preemption sequence or intersection flash.

Transit Vehicle Preemption

The preemption of signals to accommodate high-occupancy vehicles has been used in some locations with mixed success. Most transit-preemption systems are designed to extend an existing green indication for an approaching bus, and do not cause the immediate termination of conflicting phases, as would be the case for emergency vehicle preemption.

Two transit vehicle-preemption systems are very similar to the moving emergency vehicle-preemption systems. A light emitter/receiver system, using the coded flash strobe light emitter, is available. This system uses an infrared filter over the emitter, so that the flash is invisible to the human eye, and a special flash code to distinguish the transit preemption call from that for an emergency vehicle. The intersection receiver can be configured to provide both emergency vehicle and transit preemption with the same equipment.

A system using the same type of radio transmitter/receiver equipment as used in emergency vehicle preemption is also available.

Two other types of transit vehicle detectors have been used and are available. One, denoted a "passive" detector, can identify the electrical "signature" of a bus traveling over an inductive loop detector. The other, "active" detector, requires a vehicle-mounted transponder that replies to a roadside polling detector.

Drawbridge Preemption

The preemption of signals near drawbridges is similar to the operation required near railroad grade crossings. A recent study (*8*) identified three stages of drawbridge preemption—the clearance of the bridge opening area, to permit the gates to be lowered; the omission of phases during the opening; and the modification of phase timing after an opening to clear standing queues.

Preemption routines can be directly tied to the bridge's control circuitry or, where an intersection is only occasionally affected by the bridge opening, by queue detectors downstream from the intersection on the approach to the bridge.

Preemption Equipment

In the past, preemption sequences were typically generated outside of the controller unit, by some specialized external-logic package. However, with today's microprocessor-based controllers, virtually all preemption routines are performed by software internal to the controller unit. The only necessary external equipment is the preemption call detection device.

In controllers built to NEMA standards, internal preemption capability is provided as an option, and may require a special module. Several manufacturers provide a powerful set of preemption routines that can be tailored to virtually any intersection's preemption scheme. Others may require a factory-designed sequence, burned into memory for a specific intersection's requirements.

Similarly, most intersection software packages for Type 170 controllers include predefined railroad and emergency vehicle sequences, although unique intersection configurations may require specialized software development for implementation.

OVERVOLTAGE, ELECTRICAL TRANSIENT, AND LIGHTNING PROTECTION

Traffic signal control equipment has a critical operational requirement—it must continue to function continuously and reliably in a frequently harsh environment. Most physical extremes, including heat and cold, dust, humidity, and vibration, can all be protected against by quality component design and construction.

However, the electrical inputs and outputs of the controller assembly are subjected to accidental overvoltages (as may occur when exposed field conductors are contacted by electrical transmission lines), electrical transients (frequently caused by nearby motors or neon signs), or surges from nearby lightning strikes.

Minor electrical transients are well protected against in both the NEMA controller assembly (in the controller unit itself) and the Type 170 assembly, through the use of isolation devices on the various inputs. However, the possibility of more powerful surges requires additional protection equipment. A recent National Cooperative Highway Research Program study (*9*) provides valuable information on lightning protection for traffic signal equipment.

Grounding Requirements

The first step in providing the best possible protection against damaging electrical surges is to install a grounding system that brings the cabinet and other grounded facilities as close to "absolute ground" as possible. Key components include one or more properly installed ground rods, of sufficient length for the surrounding earth conditions, and the shortest possible bonding connection between the ground rod, the cabinet, and conduit system. The key to protecting the controller equipment is to provide a grounding path of least resistance, keeping surges away from the electronic equipment.

Surge-Protection Devices

Surge-protection devices are designed to route harmful surges away from the incoming conductor and direct them to the grounding system. During normal conditions, the protection device provides a high resistance to ground, so that the normal operation of the conductor is not affected. However, when a surge arrives on the conductor, the protection device must quickly (in nanoseconds or less) activate, providing a low resistance to ground and routing the surge away from the equipment being protected.

There are several types of devices used in protecting circuits against surges. Gas breakdown devices, such as spark gaps and gas-discharge tubes, can protect against high-energy surges but are slow to react and may not protect at lower energy levels. Zener and avalanche diodes are fast acting but are not capable of protecting against high energy levels. Metal oxide varistors (MOVs) act fast, but only on higher-voltage surges, and they are destroyed by high-energy surges (*10*).

Most surge protectors on the traffic-control market are hybrid devices, combining two or more different devices to provide protection across the spectrum of possible surges. Many protectors must be replaced occasionally, as degradation of the protection characteristics occurs after several surges.

Power Supply Inputs

The inputs from the electric utility's power lines are the most frequent source of damaging surges to the controller assembly. Even though a lightning strike may contact the utility's cables a mile away, surges that are potentially dangerous to the signal equipment can be transmitted over the utility's distribution system to the controller.

Ideally, the power service neutral conductor should be connected directly to the cabinet ground, although in some jurisdictions this is prohibited. The power service hot conductor, and the neutral conductor (if ungrounded), should be routed through the appropriate surge-protection device immediately upon entering the signal cabinet.

Loop Detector Inputs

Loop detectors, embedded in the roadway, can act as large antennas, picking up surges through the ground during a nearby lightning strike. Recommendations for surge protection for loop detector leads vary by detector manufacturer, some of whom indicate that external protection devices can interfere with the operation of the detector amplifier. However, protection devices designed for use with loop detector leads are available and have been used successfully without affecting detector performance.

Field and Signal Wiring

Load-switch outputs, to the signal heads at the intersection, provide another ingress point for damaging surges. The most common form of protection for these circuits is the use of an MOV on each outgoing conductor.

Pedestrian push-button circuits also provide exposure to harmful surges, particularly in the NEMA controller where the controller unit's logic common output is directly tied to the push-button terminals. Surge-protection device manufacturers recommend the tying of logic common output directly to cabinet ground and routing pedestrian detector inputs through surge-protection devices.

System Interconnect

A system-interconnect cable provides the last of the potential sources of surges harmful to the controller equipment. All cables will require protection; cables used for modem communications will require a different type of protector than those needed for an AC interconnect cable. A shielded cable will help to protect the interconnect facilities; the shield should be grounded on only one end of the cable, where it enters the cabinet.

CHAPTER THREE

DETECTORS

According to a survey developed for this synthesis (see Appendix A), most traffic signal installations in the United States today are designed to be traffic actuated, adjusting signal sequences and timing based on traffic demands currently present at the intersection. Detectors are used to determine the approach of, or presence of, vehicular or pedestrian traffic intending to cross the intersection. Detectors can also be used to provide current traffic data to traffic-responsive systems; to collect count data for planning purposes; to activate special control devices for incident-management or queue-dispersion strategies; to measure speeds; and for a host of other unique applications.

FUNCTIONS OF DETECTORS

Detectors provide for at least one of two basic functions—the determination of the presence of a vehicle or a pedestrian or the determination of the motion, or passage, of a vehicle or pedestrian. A presence detector will generate an output signal for as long as the detected object is in the area being monitored by the detector (subject to the eventual tuning out of the call by some types of detectors). A passage detector generates a short-duration output signal, based on the arrival or motion of the detected vehicle or pedestrian. Some types of detectors can provide either the presence or the passage function; others can provide both.

In vehicular intersection actuation applications, presence detection techniques typically are used for stop bar actuation; either presence or passage detectors can be used for detection of vehicles upstream from the intersection.

For systems or other applications in which volume data are desired, a detector using either a presence or passage design can be used to count vehicles. However, if occupancy data (the percentage of time a detection area is occupied, which is directly related to the density of traffic on the roadway) are also desired, then presence detection must be used.

Detectors can also be used to determine speeds. A pair of passage detectors, located a predetermined distance apart, currently provides the most accurate speed-determination technique. A single presence detector can also be used to determine speed when the length of the detection zone is known, and the length of an "average" vehicle can be estimated. The paired-detector arrangement can also be used to determine the direction of travel over the detection area.

RELIABILITY OF DETECTION EQUIPMENT

Like all traffic signal equipment, detectors must be capable of withstanding harsh environmental factors and continuing to operate over an extended life span. However, in responding to the user survey performed for this synthesis, many agencies expressed a level of dissatisfaction with the reliability of their current detection equipment.

Compounding this problem is the somewhat common feeling that detectors are an operational luxury. When an intersection detector fails, the controller can be programmed to place the affected phase on recall, so that a fixed-duration phase is timed. A failed system detector can be dropped from traffic-responsive calculations or the system itself returned to a time-of-day operation. With today's limited operating budgets for traffic engineering departments, repair of failed or broken detectors is often a low priority.

Although this may not represent a safety hazard, it does create inefficiencies in traffic movement. Actuated controllers cannot respond to the peaks and lulls in traffic during the peak hour, reducing the capacity of the signalized intersection. Systems cannot respond to variations in traffic flow, selecting a time-of-day pattern that may not be appropriate for actual conditions.

New types of detectors, and updated installation and design techniques for the types of detectors already in wide use, are helping to overcome some of the problems being encountered. The future looks promising for a more reliable detector.

VEHICULAR DETECTORS

The state of the art of vehicle detection has come a long way since Charles Adler installed a microphone detector at an intersection approach in Baltimore, Maryland, in 1928. Motorists approaching the intersection were advised to blow their car horns; the detector would sense the noise and activate a relay, sending a signal to the controller to advance to the side-street phase.

Today, a wide variety of vehicular detectors are available to the traffic engineer.

Inductive Loop Detector

The inductive loop detector is, by far, the most common form of detector in the United States. A loop of wire, embedded in the roadway as illustrated in the schematic in Figure 14, is connected to an electronic device that can measure the inductance of the loop. When a vehicle occupies the area above the loop, the inductance of the loop changes. This change is sensed by the electronic device, causing an output to be transmitted to the intersection controller or system-monitoring device (*11*).

Loop Detector Configurations

Inductive loop detectors can provide both presence and passage detection functions. In practice, the configuration, size, and

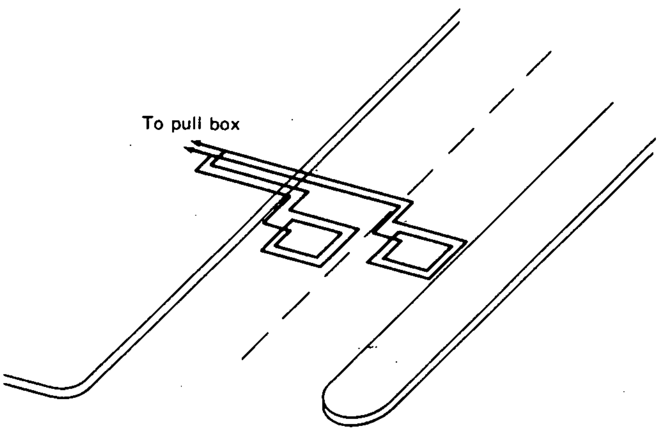


FIGURE 14 Schematic of inductive loop.

placement of the loop determines the function of the detector. Several examples are shown in Figure 15.

Presence detection is normally accomplished with a long loop, or a series of small loops, located longitudinally down the center of each approach lane. Long loops are typically 6 ft wide, and usually range in length from 20 to 70 ft. A series of 6-ft-square diamond, octagonal, or circular loops, separated by 6- to 12-ft spacing and wired together to the same detector unit, can replicate the operation of the long loop.

Long loops are normally the least expensive presence loop to install. However, they may have problems with reduced sensitivity; and, where pavement stability is a problem, they are subject to an "all-or-nothing" failure. The sensitivity problem can be addressed with a long loop incorporating a "powerhead," or small loop within a loop; or with a "quadrupole" loop, where a center longitudinal conductor and a "figure-8" winding of the loop wire will also increase the sensitivity of the loop.

The series of small loops solves both problems, in that small loops are inherently more sensitive than long loops, and should a pothole break one of the small loops, it can be disconnected from the other loops, allowing for continued detection of the approach until the loop can be repaired.

Passage detection is normally accomplished with a small loop. Although the most common design is a 6-ft-×-6-ft square loop, diamonds, octagons, and, most recently, circles are also popular. Multilane passage detection can be accomplished with two adjacent small loops, or a longer loop turned perpendicularly to the roadway.

Installation

Inductive loops are normally installed by sawcutting a slot, in the shape of the loop, in the pavement; laying in the loop wire; and sealing the wire in the slot with a durable sealant. The loop wire is extended into a pull box, where it is spliced to a lead-in cable for connection to the detector electronics in the controller cabinet. Proper installation has been shown to be a very significant factor in the life and proper operation of inductive-loop detectors (*11*).

Where loops are being installed in a new roadway, it may be practical to install a preformed loop. With loop conductors installed in a PVC conduit frame, located well under the surface of the new pavement during the paving operations, the preformed loop can provide a durable, almost maintenance-free alternative to the saw-slot installation practice.

Detector Electronics

Requirements for inductive-loop detector electronic devices are included in both the NEMA standards and the Type 170 specifications. The NEMA standards define a series of self-contained loop-detector units, designed for shelf mounting, and card-type detector units, designed to insert into a multicard detector housing. The Type 170 specifications define card-type detector units designed for insertion into the input file of the cabinet system.

The NEMA detector units are available with one, two, or four independent detector channels per unit. The card detectors used in the Type 170 system each contain either two or four independent channels, and are interchangeable with the NEMA card-type detectors.

The NEMA standards also define optional timing features, allowing for the delaying or the extension of the detector output. In the delayed-call mode, the detector will wait a user-defined period, after a vehicle enters the detection area, until it starts the output signal. In the extended-call mode, the detector will extend the output after the vehicle leaves the detection area. The Type 170 detector does not provide this capability, because it is normally performed by the software in the controller unit itself.

Magnetic Detectors

Magnetic detectors (Figure 16) comprise a small coil of wire, embedded in a protective housing and installed under the surface of the roadway, and an electronic amplifier located in the controller cabinet. As a vehicle passes over the detector sensor, the earth's magnetic field in the area of the sensor is disturbed, causing a small voltage to be generated within the coil of wire. The amplifier senses this voltage change and activates a relay output for a vehicle actuation.

Magnetic detectors work only on the passage of a vehicle (a minimum speed of 3 to 5 miles per hour is required); they cannot detect presence and therefore have limited application in many of today's intersection-detection strategies. Their primary advantage is their simple design and resistance to pavement-surface problems.

Magnetometer Detectors

The magnetometer detector is significantly different in function from a magnetic detector, although they both respond to variations in the earth's magnetic field caused by the passage of a vehicle. The magnetometer senses the variation in the density of the lines of flux caused by the passage or presence of the vehicle, causing a relay closure for vehicle actuation. As the change in flux around the vehicle is present even when the vehicle is stationary, the magnetometer detector can be used for presence or passage applications.

The detector has a sensor probe embedded in the roadway and an electronic amplifier in the controller cabinet. The probe is a

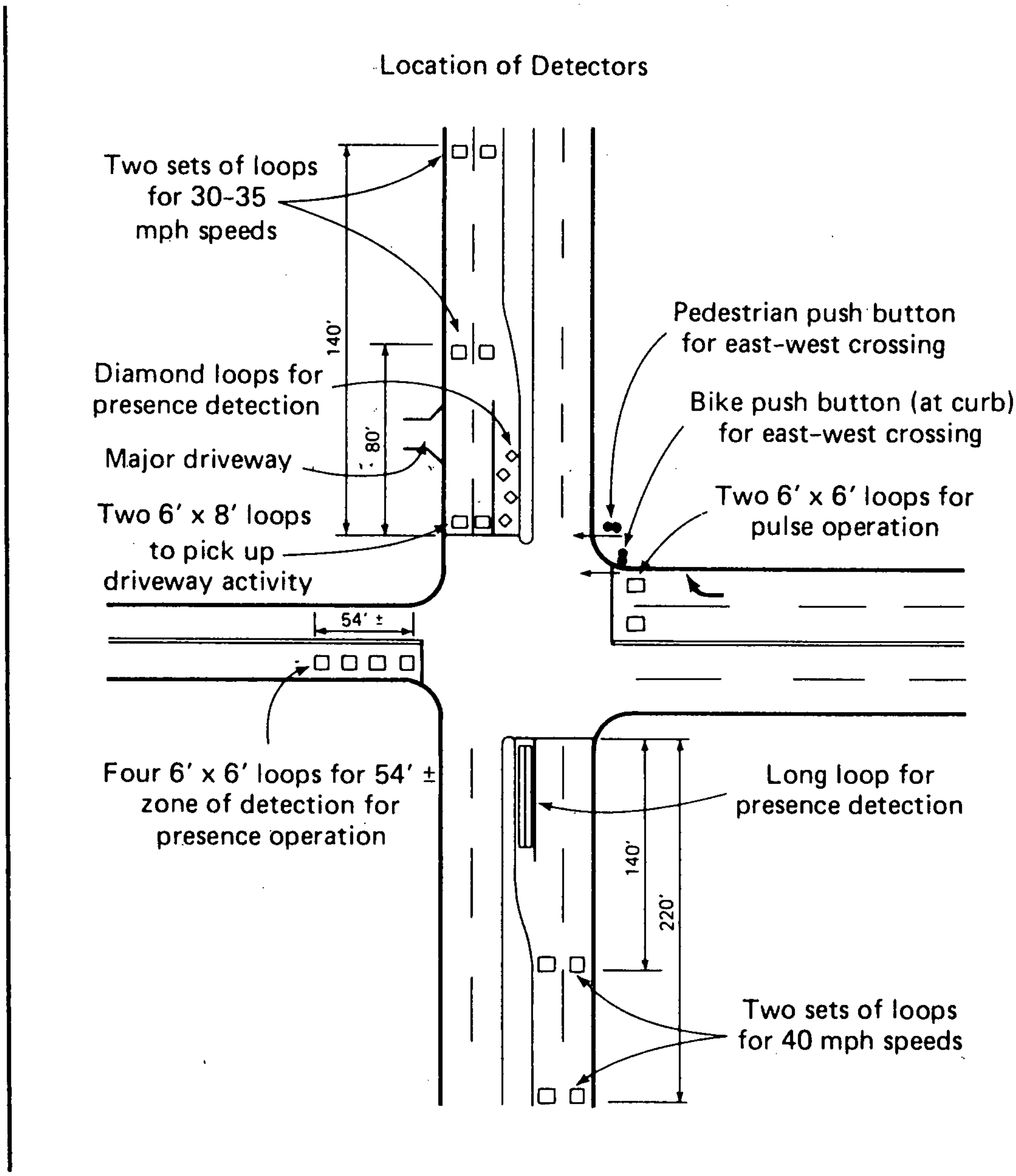


FIGURE 15 Loop detector applications.

cylinder, about 1 in. in diameter and about 4 in. long. It is installed in a drilled hole, about 1 ft deep, with the lead-in cable running through a sawcut back to the edge of the roadway. The alignment of the probe is critical to the success of the installation.

The sensor probe comprises a magnetic metal core with two wrapped windings, much like a small transformer. It is encased in a rugged plastic casing and hermetically sealed, with the winding leads extending out one end of the cylinder, as shown in Figure 17.

The magnetometer provides for a highly sensitive small-area detector. It can be used in series with other magnetometers to provide large-area presence detection; it can also be used singly to detect bicycles, provided that they are directed to the proximity of the detector sensor.

The magnetometer does not provide for sharp cutoff at the perimeter of the detected vehicle, and therefore is not recommended for occupancy and speed determination. However, it can sense the presence of two closely spaced vehicles, making it an excellent counting detector.

The NEMA standards do not address magnetometers, but the specifications for the Type 170 controller system do include the sensor probe and electronics package.

Microloop Detectors

The microloop detector is a proprietary detector probe, similar in design to the magnetometer probe, but intended to be con-

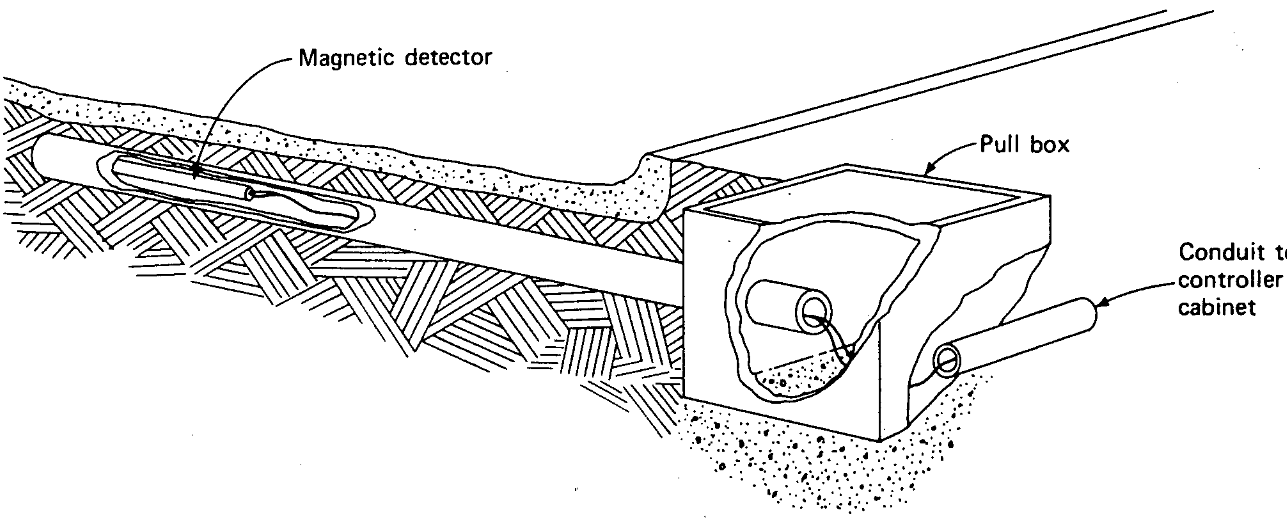


FIGURE 16 Magnetic detector installation.

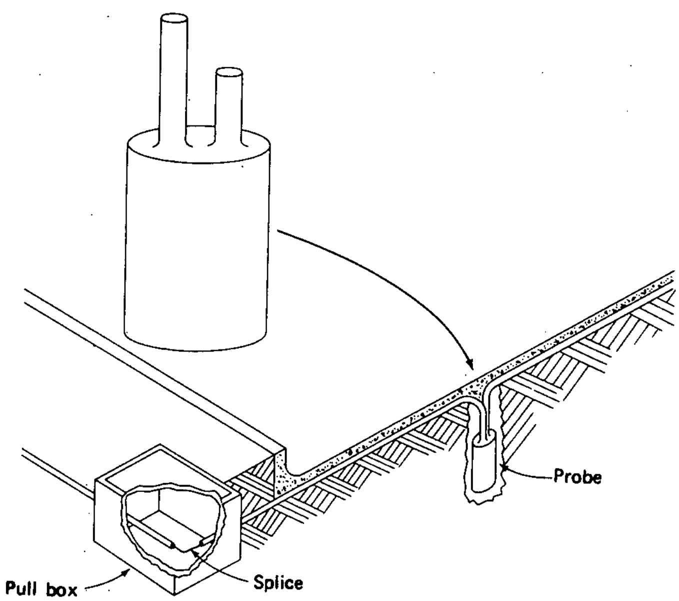


FIGURE 17 Magnetometer installation.

nected to a standard inductive-loop detector electronics unit. The microloop probe converts magnetic field intensity increases to decreases in inductance, thus activating the loop-detector amplifier.

Like the magnetometer, the microloop is designed for high-sensitivity point detection. One advantage of the microloop is that more probes per channel can be installed than with the magnetometer detector. However, it does not provide for presence detection, requiring some motion to activate the triggering circuitry of the detector.

The probe is typically installed in a drilled hole in the pavement, with the lead-in cable inserted into a saw slot back to the edge of the roadway.

Radar (Microwave) Detectors

Radar detectors operate on the Doppler effect, as a microwave signal is emitted by the detector and reflected back at the detector by approaching vehicles. The shift in frequency caused by the movement of the vehicle is sensed by the detector electronics, which causes the generation of a vehicle-actuation output. Because the detector requires motion to sense the presence of a vehicle, it cannot be used in the presence mode.

Radar and other overhead or side-of-the-road detectors continue to offer the advantages of installation without the disruption of traffic needed for pavement detectors. They permit detection where pavement is unsuitable for roadway detectors, and they also provide a good temporary detector, as may be needed during the maintenance of traffic during construction.

Infrared Detectors

Infrared detectors are relatively new on the market, and hold promise as an overhead or side-of-the-road mounted detector. Two basic types are available—the passive detector and the active detector.

The passive detector senses the thermal infrared radiation emitted by warm objects, such as motor vehicles, as they pass by the area of the detector sensor. An increase in received infrared radiation triggers the actuation output to the controller unit.

The active detector includes an infrared light source directed toward the detected approach. Approaching vehicles reflect the infrared light back toward the detector, much like the infrared focusing systems used in some of today's photographic equipment.

Ultrasonic Detectors

Ultrasonic detectors emit a high-frequency tone that is reflected at varying frequencies by approaching traffic. At least one currently available detector uses a digital distance-measuring technique, similar to autofocus cameras that use sonic ranging. A distance threshold, set by the installer, determines the location of all vehicles being detected.

Ultrasonic detectors can be mounted either directly over the lane(s) being detected or mounted on the side of the road in a "side-fire" position. These detectors can provide both presence and passage detection.

Future Detectors

Fortunately, the search for an improved vehicle detector continues, with the goal of trying to improve reliability and sensitivity while limiting installation and maintenance costs.

The VIDS (Video Imaging Detector System) detector uses digitized video-imaging techniques to track the trajectories of all traffic on an approach. A prototype system has been tested and shown to adequately track and measure the movements of vehicles in a single travel lane. A similar system using infrared imaging is also being developed.

The self-powered vehicle detector, initially developed under an FHWA research program, does not have to be physically connected to the intersection controller. Using a battery power supply, magnetometer detectors, and a radio transmitter, the detector transmits call status back to a receiver at the controller cabinet, up to 500 ft away. A major advantage of this system is the cost saving in conduit and cabling normally used in detector installations. It is also well suited as a temporary, reusable detector. However, the problems of limited battery life and a restricted number of radio channels are still to be resolved.

PEDESTRIAN DETECTORS

The accurate detection of pedestrians seems very easy, but in fact is quite difficult to accomplish. Unlike vehicles, pedestrians do not change magnetic fields or cause inductive variations. They cannot be depended on to follow a specific path, based on their intended direction of travel. And they cannot be depended upon to make a specific action to let their presence be known to the signal controller.

Detection of the visually impaired pedestrian presents the even greater problem of leading the pedestrian to the detection point and then indicating when it is safe to cross.

Pedestrian Push Buttons

By far, the most common means of detecting a pedestrian is the pedestrian push button, illustrated in Figure 18. It is simply a heavy-duty, momentary-contact switch, located conveniently to the path of the pedestrian. Pressing the button closes a circuit, which places a call on the appropriate controller detector input.

The weak link in the pedestrian push button is the pedestrian. Unlike vehicle detectors, the pedestrian push button requires a specific action to be taken to register a demand. Unfortunately, many pedestrians do not make the necessary effort, and therefore cross the intersection illegally and unsafely.

Many pedestrians do not realize that the actuation of the button extends their green time; some feel it is only there to service their needs faster. The MUTCD specifies a series of standard signs for use with pedestrian push buttons, to direct the pedestrian in their use. Many agencies are using additional signs to inform the pedestrian of the meanings of pedestrian (WALK/DON'T WALK) indications and to emphasize the need for pushing the button. Some agencies use lighted indicators on the push-button assembly to acknowledge that the call has been received by the controller unit.

Where two buttons are located on the same support, for crossing in different directions, care must be taken to clearly indicate the button's relationship to each crosswalk. When pedestrian push buttons are used to detect visually impaired pedestrians, some type of guiding device (sidewalk texturing, audible locator, or handrail) can be used to enable the pedestrian to locate the push button.

FIGURE 18 Pedestrian push button.

Pressure Mats

Pressure mats, similar to the mats used in automatic doors, have been used in some locations to detect pedestrians. The mats are installed on the sidewalk, near the end of the crosswalk. The pedestrian steps on the mat, closing a continuous-contact switch, which relays the pedestrian call to the controller unit.

The mats must be located carefully to be in the path of approaching pedestrians; barrier handrails can often be used to force pedestrians onto the mats. The mats are nondirectional, so if a pedestrian completing a crossing steps on the mat when leaving the intersection, an undesired false call will be registered. A guiderail system can help to protect against this problem.

Infrared Detectors

The passive infrared detector has also been used to detect the presence of pedestrians on the street corner. However, like the pressure mat, they do not provide for the identification of pedestrian direction, allowing the placement of false calls by pedestrians leaving the crosswalk.

BICYCLE DETECTION

From a detection standpoint, bicycles are midway between pedestrians and motorized vehicles. Although bicycles do not have to follow specific paths, most can be detected because of their metal content.

Two primary techniques are reported for detecting bicycles. The more common is the use of the pedestrian push button, which requires the bicyclist to proceed on the sidewalk to the button location and cross the intersection in the crosswalk. An advantage of this is that the pedestrian timing features can be called, ensuring the bicyclist sufficient time to cross the street.

The second common technique is to detect bicycles with vehicular detectors, most notably the inductive-loop detector. By installing a loop designed for improved sensitivity in the curb lane, bicycles can place a call and extend the green as would any motorized vehicle. One drawback to this approach is that the extension time for bicycles is usually greater than that needed for motor vehicles, and this design may not give appropriate signal timing to the bicyclist.

An alternative design dedicates a loop to the bicyclist, by locating it in the bike lane along the side of the road. This loop can be much smaller than a standard loop, increasing its sensitivity, and its output can be connected to the controller phase's pedestrian-call input, guaranteeing sufficient time to cross the street.

Finally, the passive infrared detector shows promise in the detection of bicycles, sensing the heat of the bicycle rider.

CHAPTER FOUR

SYSTEMS

Two or more signalized intersections, operating in a relationship to each other to provide for progressive traffic flow, form a coordinated system. The two basic requirements for bringing local signal controller equipment into a coordinated system are an appropriate signal system timing plan and the hardware components necessary to implement the plan.

The signal system equipment available today ranges widely in complexity and capabilities. The simplest systems are functionally identical to those installed 50 years ago; the latest generation of microprocessor-based systems provides functional capabilities exceeding most current large computer-based systems (*12*).

SYSTEM-TIMING PARAMETER DEFINITIONS

There are three basic system-timing parameters used in coordinated systems:

- Cycle—The period of time in which a pretimed controller (or an actuated controller, with demand on all phases) displays a complete sequence of signal indications. In most systems, the cycle length is common to all intersections operating together, and is called the background cycle.
- Split—The proportioning of the cycle length among the various phases of the local controller.
- Offset—The time relationship determined by the difference between a specific point in the local signal sequence (typically the beginning of the major street green interval) and a system-wide reference point.

A timing pattern or timing plan is a unique combination of a cycle, split, and offset, and may include a phase sequence change.

SYSTEM-TIMING PARAMETER SELECTION

There are two terms used to describe the technique that the system uses in the selection of these timing parameters:

- Time of Day/Day of Week—The time-of-day/day-of-week system selects system timing plans based on a predefined schedule.
- Traffic Responsive—Traffic-responsive systems implement timing patterns based on varying traffic conditions in the street.

Based on the sophistication of the time-of-day/day-of-week system, the timing plan selection may be based not only on the time of day, but also on the day of week and week of year. Some systems permit the selection of plans based upon a specific day of the year.

Most traffic-responsive systems select from a number of predefined patterns. An intermediate level of traffic-responsive control is being experimented with in a number of computerized systems. These systems update their library of predefined timing patterns based on data collected by the system, permitting the review of the timing plan by the systems engineer before it is made eligible for implementation by the system. The dynamic, real-time development and implementation of system timing based on current traffic demands has not yet been demonstrated to be effective in a large system.

BASIC SYSTEM TYPES

There are six basic categories of system configurations available today. The various types of systems provide for numerous options, including the types of local controller equipment, means of interconnection, methods of timing plan selection and implementation, and level of monitoring and reporting capabilities.

Interconnected Time-of-Day System

Applicable to both pretimed and actuated controllers, in either a grid system or along an arterial, the interconnected time-of-day system is the most common type of system found in the United States. The typical configuration for this type of system, shown in Figure 19, includes a field-located, time clock-based master controller generating pattern selection and synchronization commands for transmission along an interconnecting cable. Local intersection coordination equipment interprets these commands and implements the desired timing.

Time-Base-Coordinated Time-of-Day System

Operationally equivalent to the interconnected time-of-day system, this type of system uses accurate timekeeping techniques to maintain a common time of day at each intersection without physical interconnection, as illustrated in Figure 20. Time-base coordination is tied to the 60 Hz AC power supply, with battery backup in case of a power failure.

Time-base coordination allows for the inexpensive implementation of a system, as the need for an interconnect cable plant is eliminated. However, time-base systems require periodic checking by maintenance personnel, because the 60 Hz power company reference is sometimes inconsistent. In addition, power outages sometimes affect only portions of a system, resulting in drift between intersections that continued to operate on the power company lines and those that kept time on a battery backup. At least one manufacturer is offering a radio receiver,

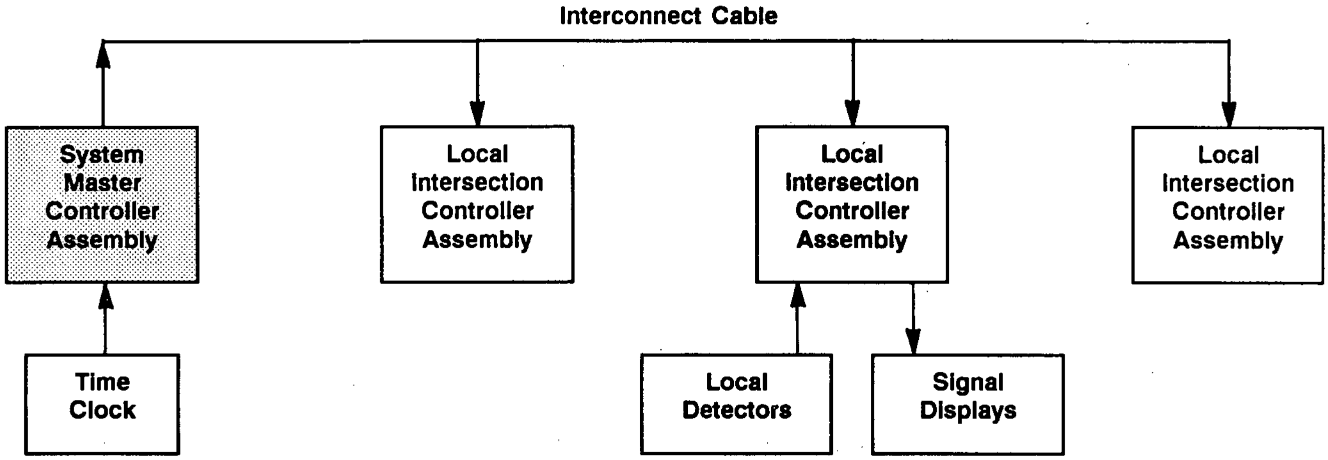


FIGURE 19 Interconnected time-of-day system.

tuned to the National Institute of Standards and Technology WWV time signal, to reset time-base coordination units to the current time of day.

Time-base coordination is also being used as a backup strategy in many computerized signal systems.

Traffic-Responsive Arterial Systems

The traffic-responsive arterial system concept, Figure 21, has been in existence for decades. Normally used with semi-actuated controllers along an arterial, the field-located system master selects predetermined cycle lengths, splits, and offsets based upon current traffic flow measurements. These selections are transmitted along an interconnect cable to coordination equipment at the local intersections.

Cycle lengths typically are selected based on volume (and sometimes occupancy) level thresholds on the arterial; the higher the volumes, the higher the cycle length level. Splits frequently are selected based on side-street volume demands, and offsets are selected by determining the predominant direction of flow along the arterial.

System sampling detectors located along the arterial input data back to the master controller along the interconnect cable. Most current systems have the capability to implement plans on a time-of-day basis as well as through traffic-responsive techniques.

Distributed-Master (Closed-Loop) Systems

The distributed-master (frequently called closed-loop) systems take the traffic-responsive arterial system one step further, adding a communications link between the field-located master controller and a central office microcomputer, as shown in Figure 22. Most systems are designed to interface with a standard personal computer over dial-up telephone lines; the connection is established only when the field master is generating a report or when the operator is interrogating or monitoring the system. Several systems can share a single microcomputer.

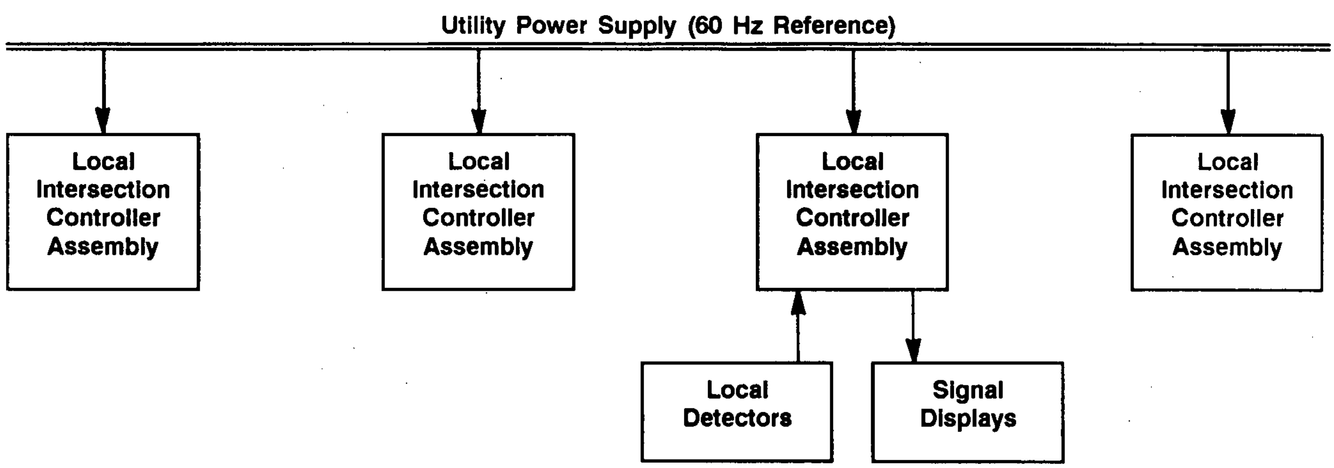


FIGURE 20 Time-base-coordinated system.

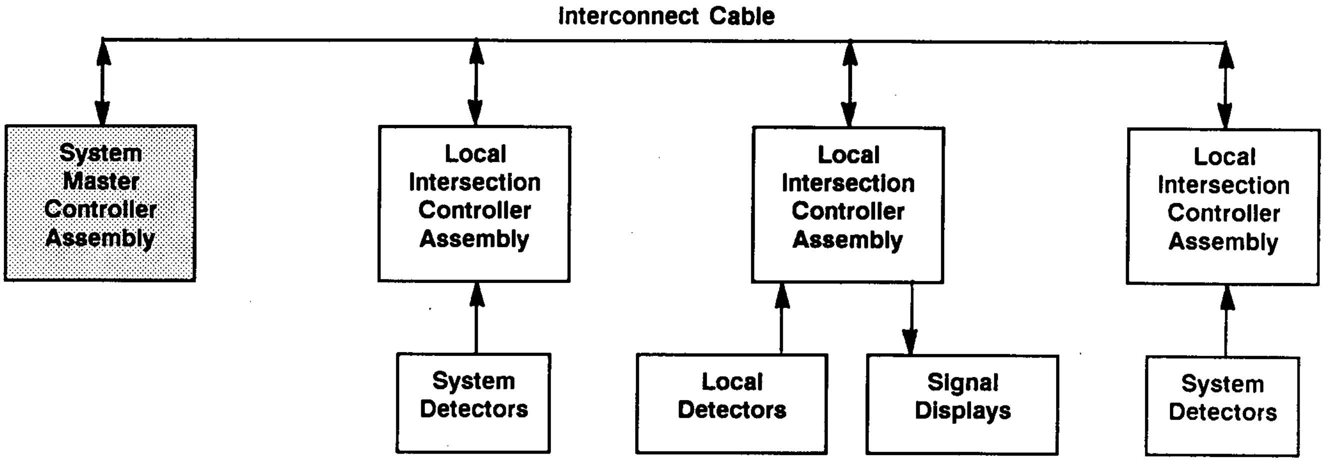


FIGURE 21 Traffic-responsive arterial system.

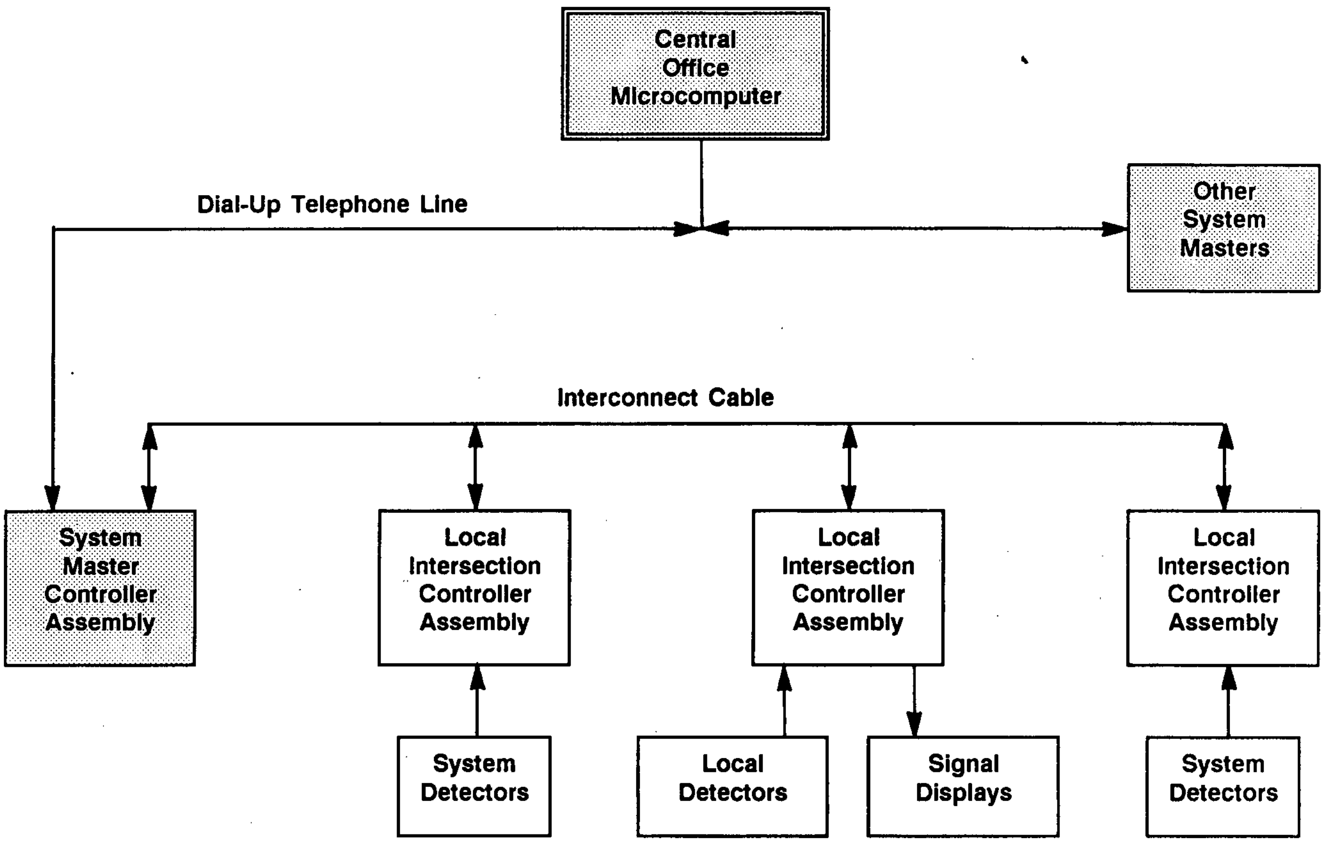


FIGURE 22 Closed-loop system.

The system permits the maintenance of the complete controller data base from the central office. Subject to constraints placed by many agencies, out of concern for potential safety problems caused by communications errors, the controller's configuration data, phase-timing parameters, and coordination patterns can be downloaded directly from the central office.

The distributed-master system provides substantial remote monitoring and timing plan updating capabilities for only a minor increase in cost—typically only the expense of the personal computer and the monthly costs of a standard business telephone line. Graphics displays are usually provided to assist in monitoring the system.

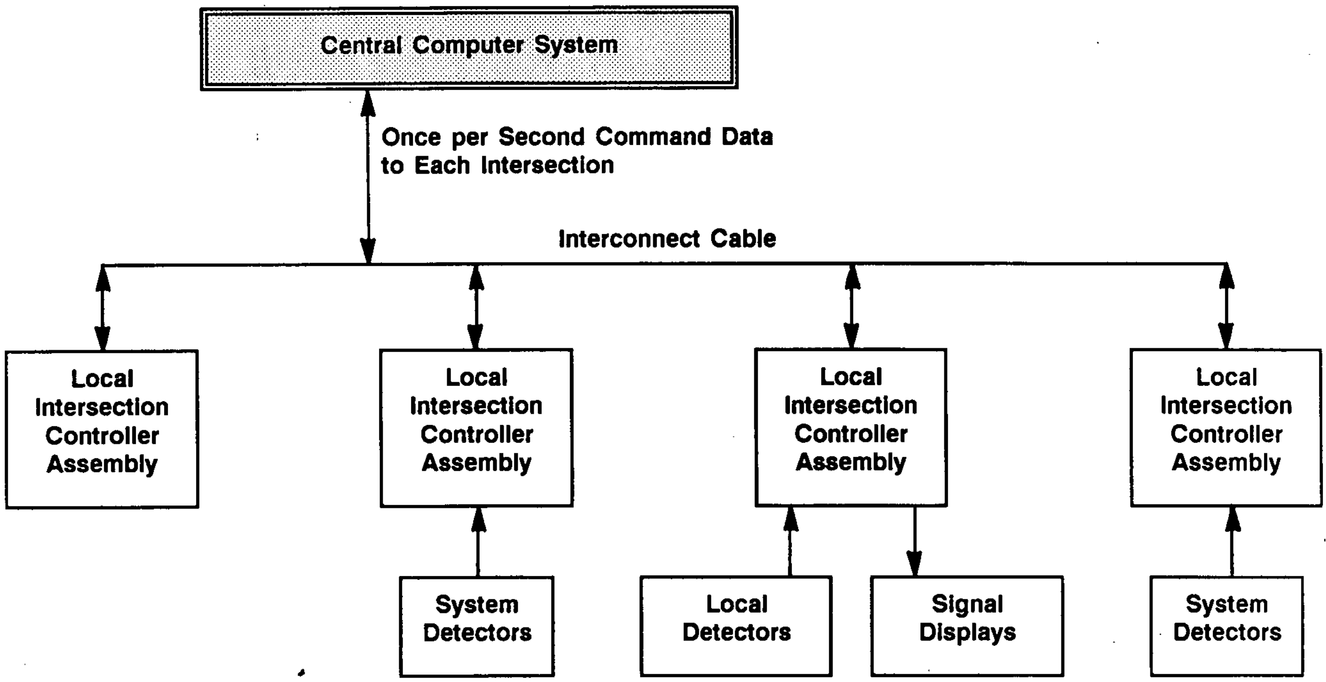


FIGURE 23 Central computer system.

Central Computer Systems (Interval-Command Systems)

The concept of directly controlling large numbers of signalized intersections from a central digital computer has been in existence for a couple of decades. The most common system installation is based on the UTCS software package developed under a contract from the FHWA. A number of similar proprietary software packages are also in use across the United States.

This type of system requires constant communications between the central computer and each local intersection, as illustrated in Figure 23. The central computer determines the desired timing pattern parameters, based either on time-of-day or traffic-responsive criteria, and issues commands specific to each intersection once per second. These commands manipulate the controller into coordinated operation.

The system also monitors each intersection once per second. Detector data, current phase green, and other information is transmitted back to the computer for necessary processing. Many systems include a large, wall-size map display, with indicators showing controller and detector status and other informational displays. Some systems include a color graphics monitoring system.

Typically, systems of this type require a large minicomputer, complete with a conditioned, environmentally controlled computer room.

Central Data Base-Driven Control Systems

The latest development in the systems field draws from the good points of both the distributed-master system and the central-computer system. Although communications are maintained continuously with each intersection, timing pattern parameters are downloaded to each controller, eliminating most of the second-by-second command data sent in the central-computer-system approach. This allows a greater number of intersections to be controlled by a less powerful computer, as shown in Figure 24.

The reduction in communications data required also allows an increase in monitoring data being returned to the computer. Thus, the complex graphics displays normally found in distributed-master systems can also be implemented in a large-scale system.

COMMUNICATIONS TECHNIQUES

Systems other than time-base-coordinated systems require some type of communications medium to maintain synchronous operation between intersections. The requirements for the communications network are dependent on the needs of the system; simpler systems typically use simpler communications networks and strategies.

Two primary options are available for system interconnection—hardwired communications, including cable networks owned by the maintaining agency as well as leased telephone or cable television lines, and radio-frequency "through-the-air" interconnection. Some new technologies are also beginning to be seen in traffic-control system use, perhaps the most important of which is fiber optics.

Hardwired Communications

Hardwired communications techniques can be used for interconnecting simple time-of-day systems to large-scale computer-

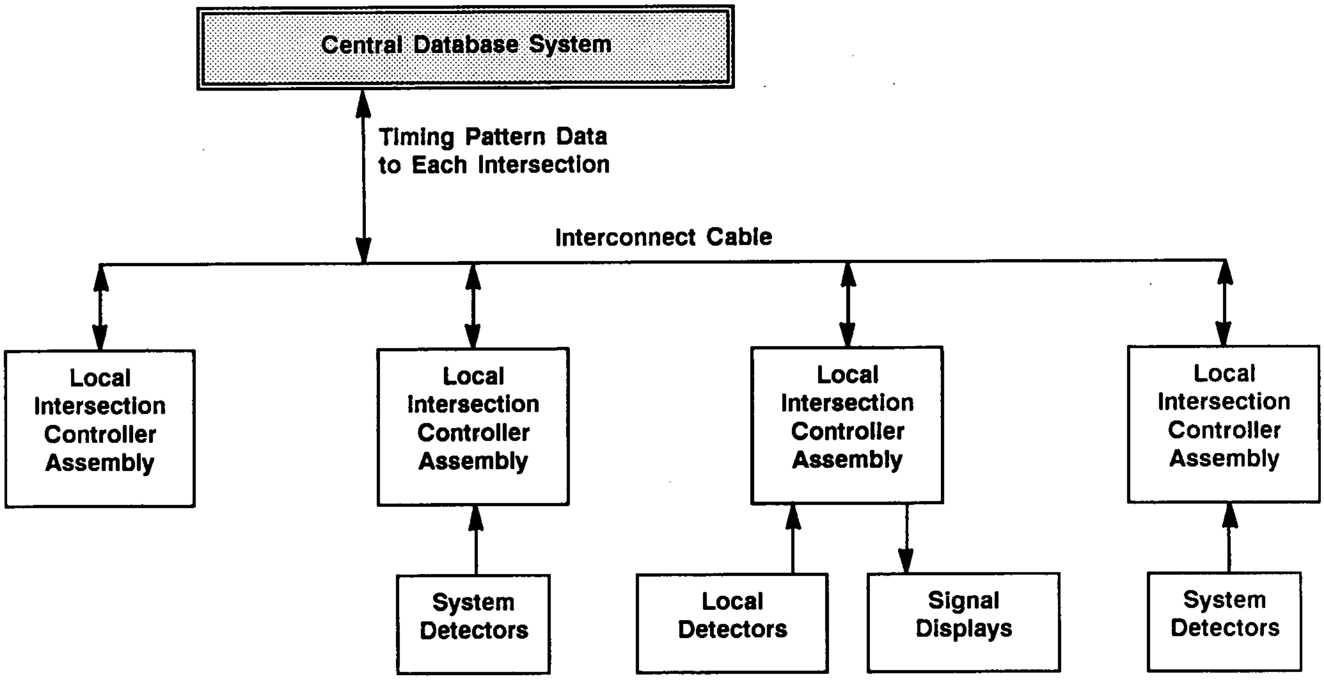


FIGURE 24 Central data base-driven system.

ized systems. Two communications techniques are predominant: switched-voltage interconnect and modulated data interconnect.

Switched-Voltage Interconnect

The switched-voltage interconnect technique finds application primarily in the interconnected time-of-day system and some traffic-responsive arterial systems. In this technique, conductors in the interconnecting cable are dedicated to specific functions, such as cycle selection, offset selection and synchronization, split selection, and special functions such as flashing operation. The master-controller unit energizes the appropriate conductors, and each secondary intersection controller responds to the common interconnect command.

The interconnect cable is typically either multiconductor signal cable, such as a seven-conductor, 12- or 14-gage cable, or paired communications cable, such as 19- or 22-gage cable. Signal cable is normally used with a 115-volt AC switched-voltage system; paired cables are normally used with a lower-voltage (24- to 48-volt AC or DC) system.

Although most systems using this type of interconnect are designed for one direction of data flow, additional cable conductors can be used to return detector or local status data to the master controller.

Modulated Data Communications

The more sophisticated systems normally use a modulated data communications format. The modulation of data allows the transmission of multiple commands, or other similar messages, over a single pair of wires. It also permits the addressing of numerous locations over a single pair of wires. Devices used to convert data into a format that can be transmitted over the cable, and to convert the transmitted data back to a useable format, are called modems, for modulator-demodulator.

The technique is applicable to twisted-pair and coaxial cables, whether agency-owned or leased from other utilities. The technique has also been used in most of the newer, high-technology communications media, such as fiber optics.

Modulated data communications have two common applications in the traffic-control systems field. Many computer-based systems communicate with each intersection once per second, transmitting a string of command data and receiving another string of monitor data. Some newer systems use modulated data communications to transfer (upload or download) system data, in blocks, to or from the local controllers.

A wide range of media are now available for modulated data communications in traffic signal-control systems. Traditionally, data communications have been transmitted over an agency-owned, twisted-pair telephone-type cable network or a leased equivalent provided by the telephone company. However, a number of state-of-the-art communications techniques have been developed or refined in the past couple of years and are beginning to see applications in the traffic signal-control field.

Advances in fiber optic technology have made a multidrop system possible, opening more possibilities for traffic control. Radio is now becoming a feasible alternative, using either the new 800 and 900 MHz public-service channels or the popular commercial cellular telephone systems. Microwave equipment has been used for point-to-point communications on large systems, including freeway-surveillance and motorist-aid systems. Finally, more traffic-control system experience has been gained from coaxial cable and CATV systems, giving more definition to this alternative's capabilities and limitations.

LOCAL SYSTEM HARDWARE

Neither central computers nor communications networks are sufficiently reliable to directly control signal displays. Therefore, virtually all traffic signal controllers made today have the capability of incorporation into any of the coordinated systems described in this chapter. Some can connect directly with the system's communications facilities, whereas others require either internal or external system interface devices.

Electromechanical Pretimed Controllers

Although rarely used in new installations, electromechanical pretimed controllers are readily adaptable to a wide range of systems. Their most common application is within an interconnected time-of-day system, in which a seven-wire interconnect system can input directly into the controller's dial selection and reset circuitry. A three-dial controller can generally provide three-cycle, three-offset-per-cycle operation. Some electromechanical controllers also provide for three splits per cycle.

Electromechanical controllers can also be incorporated into the more sophisticated systems by using an external interface device to issue commands that manipulate the normal operation of the controller. The most common case is the "dial control" technique, in which the system calls for a dial with a short cycle length, typically timing only the necessary minimums and clearances. The reset circuitry is used to start and stop the dial, at a reset key in each extendable green interval, to vary cycle lengths and splits in accordance with the desired timing plan.

Solid-State (Microprocessor-Based) Pretimed Controllers

Solid-state pretimed controllers are designed to provide an operation functionally equivalent to the electromechanical controllers. As such, they can provide both the simple dial/split/offset interconnect selection of the electromechanical controllers, as well as the externally manipulated dial-control technique for more sophisticated systems.

Time Clocks

Time clocks can be either electromechanical or solid state in design, or even internal to the controller unit, and provide one or more circuit closures on a time-of-day, day-of-week basis. These clocks do not provide the accuracy necessary for coordination purposes; they can be used to implement operational changes, such as the initiation or termination of flashing operation, the omission of phases, or the selection of timings.

Dial Coordination Devices for Actuated Controllers

Dial coordination units can be used to implement an actuated controller into a time-of-day or traffic-responsive arterial system. The units were originally electromechanical in design, and functioned similarly to the dial-selection and reset capabilities of electromechanical pretimed controllers. A standard multiconductor interconnect selected the appropriate cycle length and offset, and the coordination unit output control signals (holds and force-offs) to manipulate the actuated-controller unit.

These devices are now microprocessor-based in design, either as standalone devices or internally to the controller unit. Some are able to provide four cycle lengths, three offsets, and three splits per cycle, and not only issue holds and force-offs but also generate permissive periods for enhanced system operation.

Time-Base Coordination Devices

By adding an accurate clock to a microprocessor-based dial coordination unit, the capability of coordination without physical interconnection is possible. Time-base coordinators have been available for the past decade; the original units were standalone in design, although most controller units today allow internal time-base coordination as an optional feature.

The time-keeping function of the coordination unit is based on the 60 Hz line frequency of the utility serving the intersection. This frequency is usually well regulated by the utility, with any fluctuations corrected on at least a daily basis. However, should two adjacent intersections be served by different electrical generating stations, there is the potential for minor discrepancies between intersections.

During a power outage, most time-base coordinators maintain the correct time using a battery-operated, crystal-controlled backup clock. As noted earlier, time-base systems are also subject to drift.

Distributed-Master System Coordinators

The local system equipment for a distributed-master or closed-loop system takes the time-base coordinator one step further, adding a modem for communications with the on-street master controller and, ultimately, the central computer. The on-street master transmits timing plan selection (cycle/split/offset) information to the local coordinator and receives, in return, local controller and detector status information. In addition, timing pattern parameters can be downloaded to the local coordinator from the on-street master or central computer.

The coordinator can be a standalone unit, adaptable to any type of controller unit, or it can be internal to the controller. If an internal design is used, the system can be designed to access the controller's data base, allowing the downloading of changes to controller parameters from a central site.

Should communications to the coordinator be interrupted, the intersection will revert to backup, time-base coordination operation.

Central-Computer (Interval-Command) System Interface Units

To provide the communications and control interface between the central computer in an interval-command type of system and the local intersection controller, an adapter incorporating a modem and input-output circuitry is required. Although this device could be (and occasionally has been) incorporated into the local controller unit, the uniqueness of the communications formats for each system and the desire to use existing controller equipment usually makes it more practical to use an external unit for this function.

The adapter receives the once-per-second command string from the central computer and converts the appropriate command bits into circuit closures, issuing holds, force-offs, and other commands to the controller unit. The adapter also typically senses the green outputs of the controller unit and the status of several system detectors, and encodes them for transmission back to the central computer.

Central Data Base-Driven Control System Interface Units

As the central data base system is a new concept, the interface hardware for these systems has not yet become commonplace. Functionally, the local interface is very similar to that used in a distributed-master or closed-loop system. It is anticipated that most controller units will be able to perform this function internally, as an extension of the closed-loop type of operation.

SYSTEM MASTER HARDWARE

For all interconnected systems, some device must serve as the master for the system. Master hardware varies considerably between the different types of systems.

Interconnected Time-of-Day System

The master for an interconnected time-of-day system can be a pretimed controller or a time-base coordinator. The pretimed controller can be either an electromechanical or microprocessor-based controller but must have time clock capabilities to allow for multiple-dial, split, and offset operation. The cycle generator (dial unit in an electromechanical controller) outputs the synchronization pulse required for the interconnect system.

A time-base coordinator used as a master can either be a standalone device or be incorporated in the local intersection controller. The master would generate the required cycle, split, and offset selection interconnect outputs.

Traffic-Responsive Arterial Systems

The on-street master for an arterial traffic-responsive system is a specialized hardware-software combination to process traffic detector data and select the appropriate timing plan. Most currently available systems use a master controller based either on the applicable portions of the NEMA standards (and are, in fact, often a modified version of the manufacturer's NEMA intersection controller) or a specialized software package for a Type 170 or Type 179 controller unit.

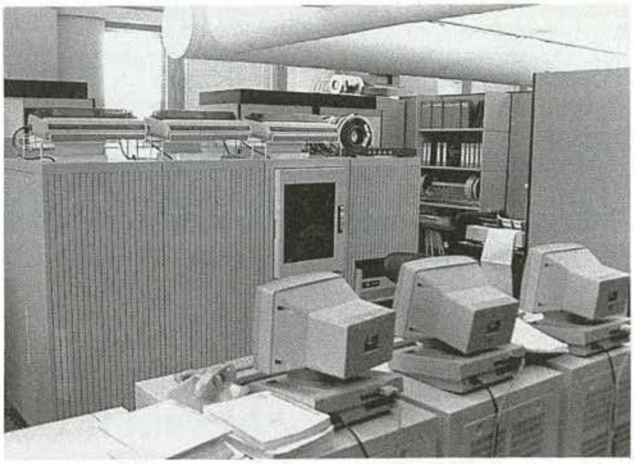


FIGURE 25 Central computer installation.

Distributed-Master (Closed-Loop) Systems

The master equipment for the closed-loop systems includes two major components: (a) the on-street master controller and (b) the centrally located microcomputer. The on-street master is very similar in operation to the master for the traffic-responsive arterial system, except that the interconnection with secondary controllers is based on modem communications. Like the traffic-responsive arterial systems, the master controller can either be based on NEMA environmental standards, with a unique hardware design developed by the manufacturer, or a specialized software package for use in a Type 170 or 179 controller unit.

The central microcomputer is typically an upper-level personal computer with high-quality color graphics, a printer, and a modem for initiating and receiving dial-up telephone connections with the on-street master controller. One central microcomputer can oversee the operation of numerous on-street masters and local intersection controllers.

Central Computer Systems

Systems centered around a central computer do not have a master controller, per se, but instead are manipulated directly by the computer. Major components in such a system include a dedicated computer system, typically a minicomputer suited for process control (Figure 25); operator interface devices, including terminals, printers, map display, and console (Figure 26); communications interface equipment; and auxiliary devices, including environmental and electrical conditioning equipment, and fire protection (Halon) systems.

Software to operate the system is normally tailored to the functional requirements of the system and the operating characteristics of the minicomputer and communications devices. Most systems are based on the public-domain UTCS package, although a number of proprietary software packages are also available from systems consultants.

Map displays have traditionally been a component of large signal systems. The large (wall-size) graphics use discrete lamps to indicate system, detector, and intersection status. The improved capabilities of video color graphics have begun to make the map displays obsolete, because they require significant levels of maintenance and are difficult to update when new intersections are added.

Central Data Base-Driven Systems

This latest generation of large-scale systems reduces the need for high-power computing equipment at the central site. With the need for second-by-second transmission of commands to each intersection eliminated, the central control function can be accomplished by less powerful minicomputers or even a network of microcomputers sharing data and tasks. A side advantage is that the extensive environmental conditioning needed for larger minicomputers can often be eliminated for these desktop computers.

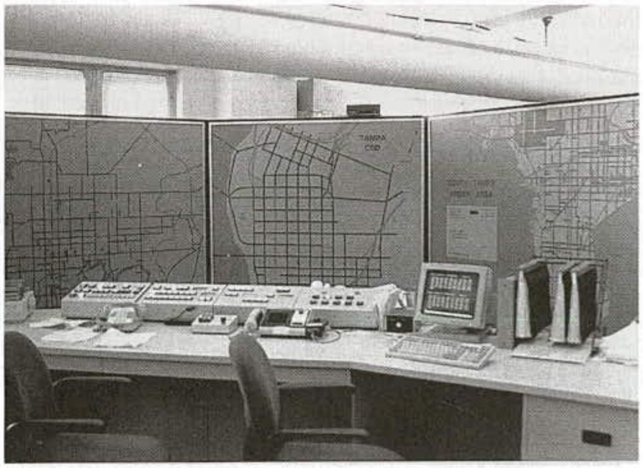


FIGURE 26 Map display.

CHAPTER FIVE

SIGNAL DISPLAY EQUIPMENT

The most visible components of a traffic signal installation are the various vehicular and pedestrian signal heads and their supporting structures. Most members of the motoring public are unaware of the complexity of controller, detection, and systems elements of a signal installation, but all are familiar with the appearance of traffic signal display equipment.

Although the three-color vehicular signal face has been around for more than 50 years without significant visible changes, new materials and manufacturing techniques have made them easier to maintain and install. Pedestrian signals have undergone several design changes since their initial use, including the colors and design of their indications. Mounting locations and techniques have also changed over the years, although with substantial variations by geographical area.

HIGHWAY TRAFFIC SIGNALS

The National Electrical Manufacturers Association defines highway traffic signals as "Any power operated traffic control device (except a sign or a barricade warning light or steady burning electric lamps) by which traffic is warned or is directed to take some specific action" (*2*). This would include signals for both vehicular and pedestrian traffic.

Conventional Vehicular Traffic Signals

Design requirements for vehicular traffic signal heads are mandated in the MUTCD and are also addressed in standards published by the Institute of Transportation Engineers (ITE) (*13, 14*). The ITE standard defines the following terms relating to signal displays:

- Signal Head—"An arrangement of one or more signal lenses in signal faces which may be designated accordingly as one-way, two-way, etc."
- Signal Face—"That part of a signal head provided for controlling traffic in a single direction. Turning indications may be included in a signal face."
- Signal Section—"That part of a signal face containing an optical unit."
- Optical Unit—"An assembly of lens, reflector, lamp, and lamp socket, with the necessary supporting parts to be used for providing a single signal indication." Some currently available signals use variations of the defined components of the optical unit.
- Signal Indication—"The illumination of a traffic signal lens or equivalent device or a combination of several lenses or equivalent devices at the same time."

The Institute of Transportation Engineers defines "sun phantom" as the effect of an outside light source (typically the sun, at a low angle behind the observer) entering the optical unit and being returned in such a manner as to present the appearance of the optical unit being illuminated.

Vehicular traffic signals are available in two sizes—the smaller size having an 8-in.-nominal-diameter lens and the larger with a nominal 12-in.-diameter lens. Applications for the two sizes are defined in the MUTCD.

Housing Materials

Signal head housings can be constructed from either cast aluminum or plastic (typically polycarbonate) materials. Each alternative provides its own set of advantages and disadvantages.

Aluminum signals must be painted, both at the time of original manufacture and at regular intervals after installation, to maintain an attractive appearance. Plastic signal heads have the color molded into the plastic material, and do not need to be painted during the life of the installation.

Plastic signals are lighter than aluminum signals, an advantage when it becomes necessary to add signal heads to an existing support structure. However, being lighter, plastic heads will swing in the wind more when used in a free-swinging overhead span-wire installation.

Currently available plastic signals typically do not have the strength of aluminum signals, and have shown a tendency to break when used in a top- or bottom-mounted rigid installation. The Florida Department of Transportation, which uses a two-cable span-wire support system with rigid top mountings, now requires that the top section of the signal, where stresses are higher, be aluminum, although lower sections may be plastic.

Visors typically are made of the same base material as the housing (i.e., sheet aluminum for cast aluminum heads, or sheet plastic for plastic heads). Yellow plastic visors should be coated with an opaque material on the inner surface to eliminate light transmittance through the plastic material.

Signal Lenses

Traffic signal lenses are designed to add color and direct light to the approaching motorist. The outer surface of the lens has a convex shape and is smooth to avoid the collection of dirt. The inner surface of the lens is concave and is patterned to best redirect the light from the lamp and reflector to the roadway approach. The lens is designed to be oriented in relation to the roadway, and is embossed with the word "TOP" to indicate the proper orientation.

Lenses can be made from either glass or plastic material. As was the case with signal housings, each material has advantages and disadvantages.

Glass lenses are heavier than plastic lenses, a drawback if weight of the signal head is a concern. Glass lenses will break if hit by a stone or bullet, whereas plastic lenses will usually remain intact after all but the most severe impacts.

Although both materials can meet or exceed ITE standards for light transmission, many engineers feel that the glass lens usually provides better light transmission, and thus a better indication. Some plastic lenses will discolor, and even melt, when larger wattage bulbs are used in indications that are illuminated for long periods of time; a prime example is the arterial green indication at a very-low-volume semi-actuated intersection.

Arrow lenses can either have the arrow pattern embossed, with uniform prismatic diffusion surface and opaque masking on the inner surface of the lens, or masked, with an opaque coating, on the outer surface of a standard lens. This second option requires care in selecting the proper orientation of the lens, because an upside-down lens will provide significantly less intensity. A third option for providing an arrow indication is the use of a metal mask, the same size as the lens and with a cutout arrow symbol. The mask is placed in front of a standard circular indication lens, and can be rotated in any direction without concern about the intensity of the indication.

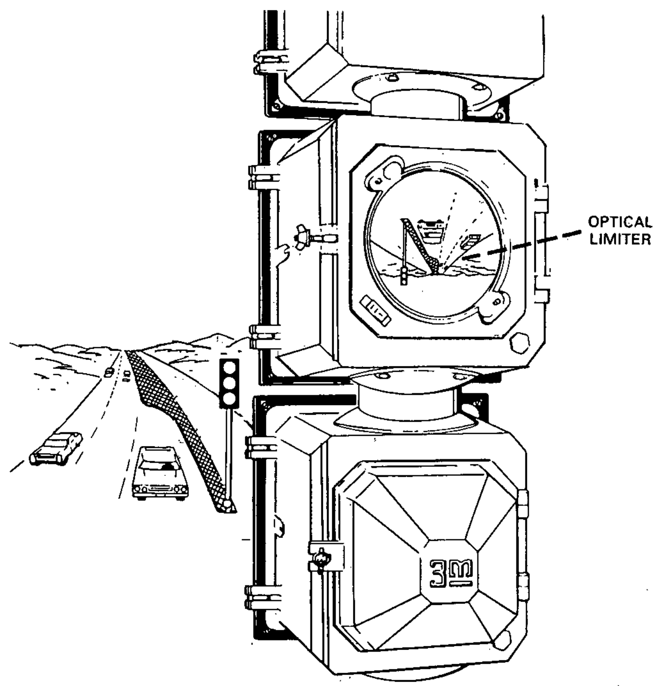
Signal Lamps

Signal lamps for traffic signal applications are specially designed to provide a long life in harsh environmental conditions, including the vibrations encountered from wind, passing vehicles, and mounting structures. Standards for signal lamps have been developed by ITE (*15*) and include four terms with which traffic engineers should be familiar:

- Light Center Length—The dimension from the center of the filament to the tip of the base of the lamp. An improper light

GENERAL

- **Aim the YELLOW indication first.**
- **Open the lamp housing.**
- **Loosen thumb screws and remove the lamp collar and diffuser.**
- **Look AT the clear glass optical limiter—not THROUGH it—to view the *inverted* image (seen best from a distance of one or two feet). What you see shows where the indication can be seen.**
- **If a portion of the black interior of the case is visible, move sideways or back to eliminate.**



Effective visibility requires careful *aiming* and *masking.* AIMING consists of tilting and rotating the signal *to center* the image (seen on the optical limiter) of the portion of roadway to be controlled.

FIGURE 27 Programmed visibility signal.

center length will result in the uneven illumination of the signal lens.

- Rated "Initial" Lumens—The average amount of light produced by a sample of lamps operating at rated voltage, after having been seasoned to ½ to 1 percent of rated life.
- Rated Life—The average of burning hours for a sample number of lamps operated at rated voltage and defined operating conditions. All traffic signal lamps should be designed to provide a minimum rated life of 6000 hr.
- Rated Voltage—The design operating voltage of the lamp. Operating a lamp at higher than rated voltage will provide higher light output, with reduced life; operating a lamp at less than the rated voltage will extend life at the expense of light output.

Most filaments for traffic signal lamps have a "U" or "W" design; to maximize the life of the bulb, the open side of the filament should point up, so that one section of the filament is not heated by a section below it.

Reflectors

The reflector directs the light output from the lamp forward through the signal lens. The reflector has a parabolic shape, and is designed for the lamp filament to be located at the focal point of the parabola—thus the need for a specific light center length of the lamp. The reflector, working with the visor and lens, is designed to minimize the sun phantom effect.

Reflectors are available in three materials: mirrored glass, specular anodized aluminum, and metalized plastic. Mirrored glass usually gives a more intense indication but is subject to breakage by impact and damage by water intrusion into the head. The aluminum reflector is lighter in weight and will not break, although corrosion is occasionally a problem, particularly in salt spray areas. The plastic reflector has not seen significant usage in vehicular signals, although it has been used in some pedestrian signals.

Lamp Sockets

Lamp sockets must be made of a material capable of resisting the heat generated by the lamp, and are designed to rotate to permit the proper orientation of the lamp filament. The socket is positioned to give the correct filament/focal point relationship for maximum illumination of the lens.

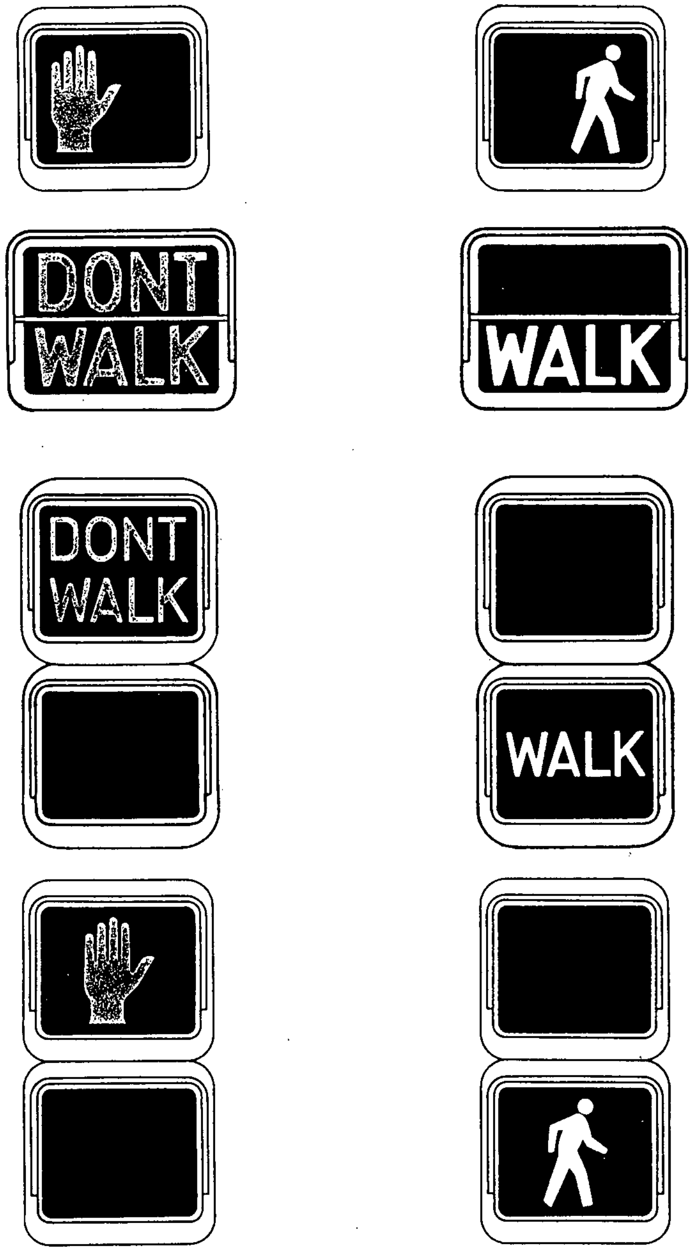


FIGURE 28 Pedestrian signals.

Programmed Visibility Signals

Programmed visibility (or optically programmed) signals are designed to direct their light output to user-specified sections of the roadway approach. Typical applications include adjacent-lane programming, in which an indication for one lane is to be veiled from an adjacent lane; skewed-intersection programming, in which geometric conditions would allow motorists on one approach to see indications for the other approach, if standard signals were used; and closely spaced intersections, in which a far-side indication conflicts with a near-side indication.

Each section of the programmed visibility signal has a flat front lens with an internal fresnel lens pattern, two convex lenses (one clear and one frosted) sandwiched together at the rear of the signal, followed by a sealed beam bulb mounted in a hinged rear-access door. Opening the door and removing the frosted lens permits the user to view the roadway approach, and, using a special foil-based adhesive tape, mask out the areas of the roadway on which motorists should not be able to see that indication, as shown in Figure 27 (*16*).

These signals require a rigid mounting; mast arm, side-of-pole, and post top mountings are best. Span wire mountings can be used with a taut messenger and bottom tether to prevent twisting and swinging in the wind. Locating the signal on the extension of the line dividing adjacent lanes provides the best adjacent lane veiling; a high mounting location provides the best distance-limiting operation.

Dual-Indication Arrows

The introduction of the yellow arrow indication in the 1971 MUTCD presented a dilemma for many agencies whose existing signal heights would not permit the addition of a yellow arrow section to a protected permitted left turn signal. As an alternative to replacing signals with a five-section cluster, some agencies opted for a dual-indication arrow section, in which both a green and a yellow arrow can be displayed.

Some current dual-indication arrows use fiber optic techniques to illuminate a series of small circular lenses, arranged to form an arrow, mounted in an insert that fits into a standard signal section housing. Two separate bulbs, one for the green and one for the yellow, emit light through color filters into bundles of glass fibers that lead to the display lenses. At least one manufacturer recently has introduced a dual-color arrow indication using high-intensity LEDs to generate the arrow display.

Pedestrian Signals

Signals for pedestrians include a number of different legends, housings, and illumination techniques. Two sets of legends are defined in the MUTCD—word legends, with an orange DON'T WALK and a white WALK; and symbols, with an orange upraised hand and a white walking man. The symbols, which were first approved in a 1977 change to the MUTCD, are gaining acceptance because of their better legibility and recognition by non-English-speaking pedestrians. As shown in Figure 28, two primary types of signal housings are available; one uses a separate section for each indication; the other combines both indications into a single housing. The first type uses incandescent lamps and is virtually identical to a standard vehicular signal. It comes in two standardized sizes; the smaller size is limited by the MUTCD to crosswalks less than 60 ft in length.

The single housing design has been adapted for incandescent, neon, fiber optic, and now LED illumination techniques. Incandescent word legend designs use a three-line legend lens (orange DON'T/orange WALK/white WALK), two lamps, and a compartmentalized reflector to illuminate the appropriate displays. Neon, LED, and fiber optic word legend designs use a clear two-line (DON'T/WALK) lens, with the light source providing the color to the appropriate displays. Symbol legends can be illuminated by any of the four techniques.

Fiber optic, LED, and neon displays can provide a substantial energy saving over the incandescent displays; they also reduce the potential for the sun phantom effect. However, the incandescent fixture, being electrically simpler, may be easier and less expensive to maintain.

A louvered "eggcrate" visor can also help to reduce the sun phantom, and eliminates the need for a longer standard visor. However, eggcrate visors are subject to accumulations of snow and ice that can block the indications.

Pedestrian indications for the visually impaired are not discussed in the MUTCD, but appear to be receiving some interest as the rights of the handicapped pedestrian are becoming better defined. Two categories of signals are defined—an audible signal and a tactile signal.

Audible signals have been used experimentally for years. Currently available devices include electronically generated chirping sounds, often with different tones to differentiate between the safe direction of crossing.

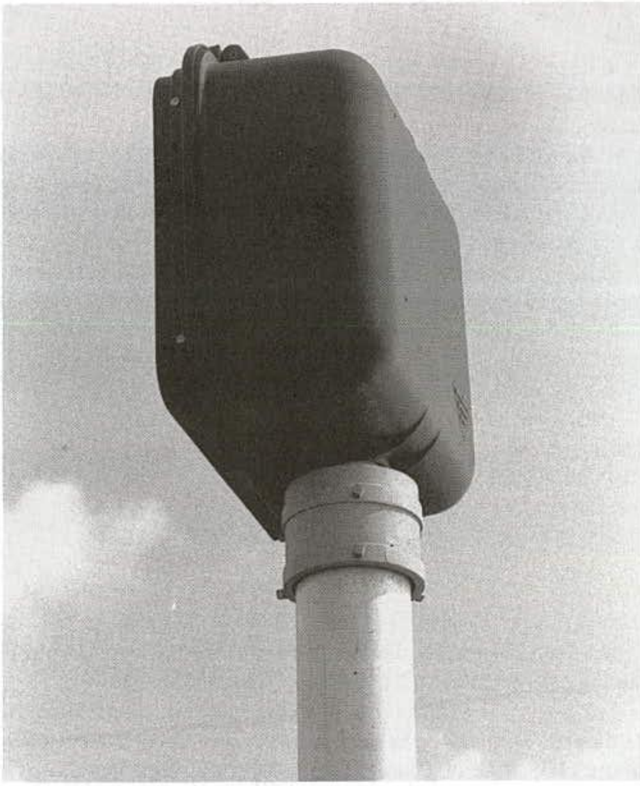


FIGURE 29 Post top mounting (slipfitter).

Tactile signals are typically incorporated into the pedestrian push-button assembly or other pedestal device near the ends of the crosswalk. The signal generates a vibration when it is safe to cross; an approaching pedestrian would locate the device and rest a hand on it until the vibration signal is sensed. Organizations for the visually impaired have mixed opinions concerning the effectiveness of special traffic-control devices. Many prefer that their members learn to cross based on listening to the sounds of traffic, feeling that audible signals are an annoyance to nearby residents, and that tactile signals are difficult to locate. However, with multi-phase actuated controller equipment, sensing when it is safe to cross a busy signalized intersection may be difficult (*17*).

SIGNAL MOUNTING EQUIPMENT

Although the requirements for signal placement are well defined in the MUTCD, the actual techniques used to mount traffic signals vary widely across the country. Signals can be mounted at the side of the road, on the tops of pedestals, on the side of poles, or over the roadway, suspended from span wire cables or mounted on rigid cantilevered mast arm structures (*18*).

Pedestal and Pole Mounting of Signals

Pedestals and poles can be used to mount both vehicular and pedestrian signals, although the technique is becoming less popular for vehicular signals because of the improved visibility

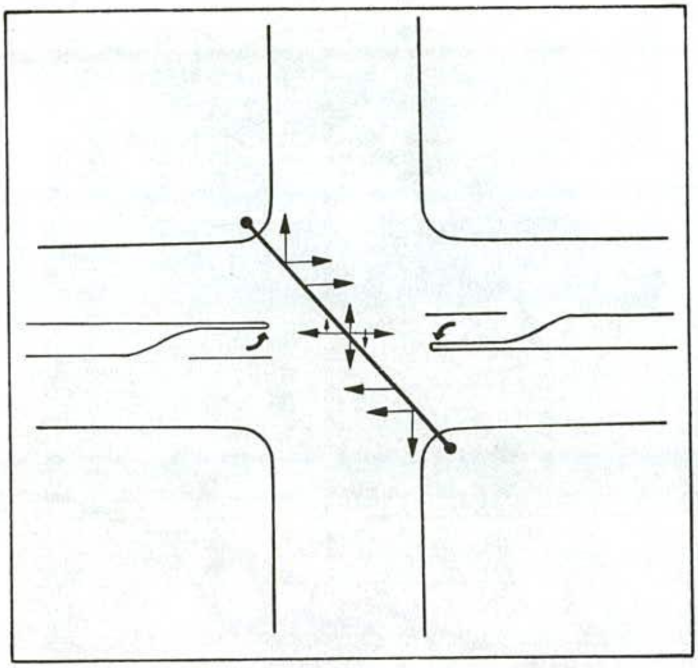


FIGURE 30 Diagonal span-wire mounting example.

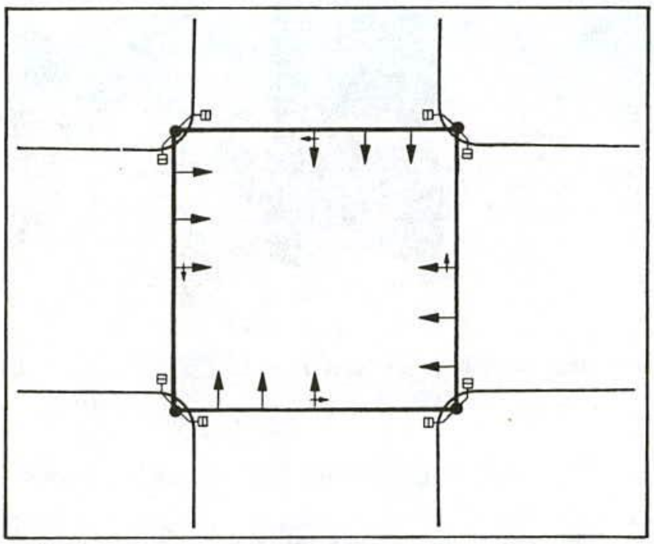


FIGURE 31 Box span-wire mounting example.

that can be obtained by an overhead mounting. Pedestals are vertical structures designed to mount vehicular signals at a height of 8 to 15 ft above the roadway, or pedestrian signals at a height of 7 to 10 ft above the sidewalk. Pedestals have been made from a wide range of materials, including 4-in.-diameter steel pipe, tapered and straight aluminum tube, cast concrete, and fiberglass. Designs include either the incorporation of an anchor mounting base, or the embedding of the upright directly into the ground. However, a breakaway design must be used whenever the support falls within a roadside recovery area.

FIGURE 32 Monotube mast arm assembly.

Mounting of signals on the top of tubular supports typically is done with a cast slipfitter cap, an adapter that fastens to the top of the support with setscrews, and provides one or more threaded hubs for standard signal mounting hardware, as shown in Figure 29. Cast concrete pedestals typically include a pipe nipple cast into the top of the support, for attaching signal hardware.

Signals can also be mounted on the sides of utility, lighting, or signal support poles, at the same elevations used for pedestal mounting.

Span-Wire Mounting Techniques

Suspending signal heads over the roadway from cables stretched between two poles has long been an appropriate signal mounting technique. Span-wire mounting provides a convenient attachment location for over-the-roadway signal displays, typically with a much lower installation expense than a mast arm or comparable structural mounting configuration. However, span-wire installations do not provide the mounting rigidity available with other structures, and may also present an objectionable, unaesthetic appearance.

Span-wire installations include two key components—the supporting poles, called strain poles, and the cable assembly. Strain poles are designed to withstand the substantial forces placed on the cable attachment point by the weights of the signal heads on the long span cable. Poles include tubular steel structures, either directly embedded or mounted, through an anchor base assembly, to embedded anchor bolts; timber poles, which typically need guying to help resist the bending moment of the pole; and embedded precast concrete poles.

Supporting cables typically are made of high-strength galvanized wire cable. Typical installations vary by location; some

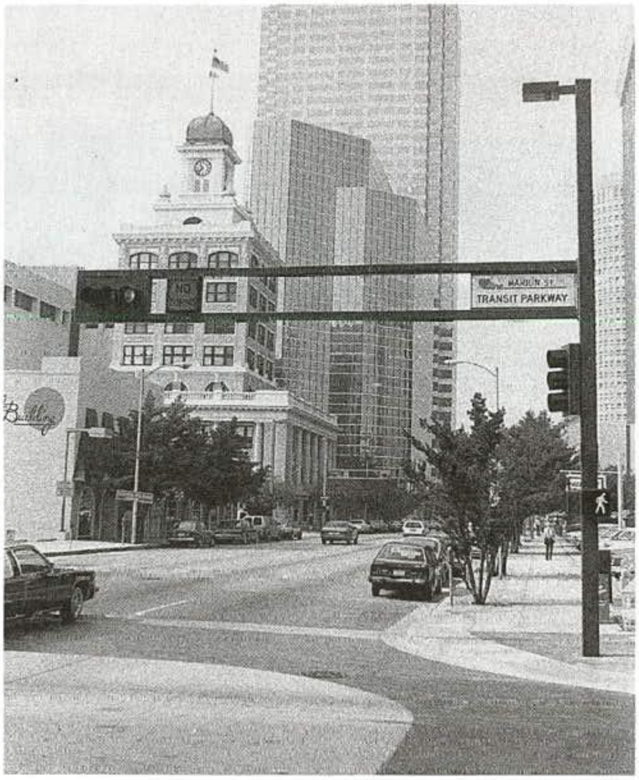


FIGURE 33 Monolithic (aesthetic) mast arm assembly.

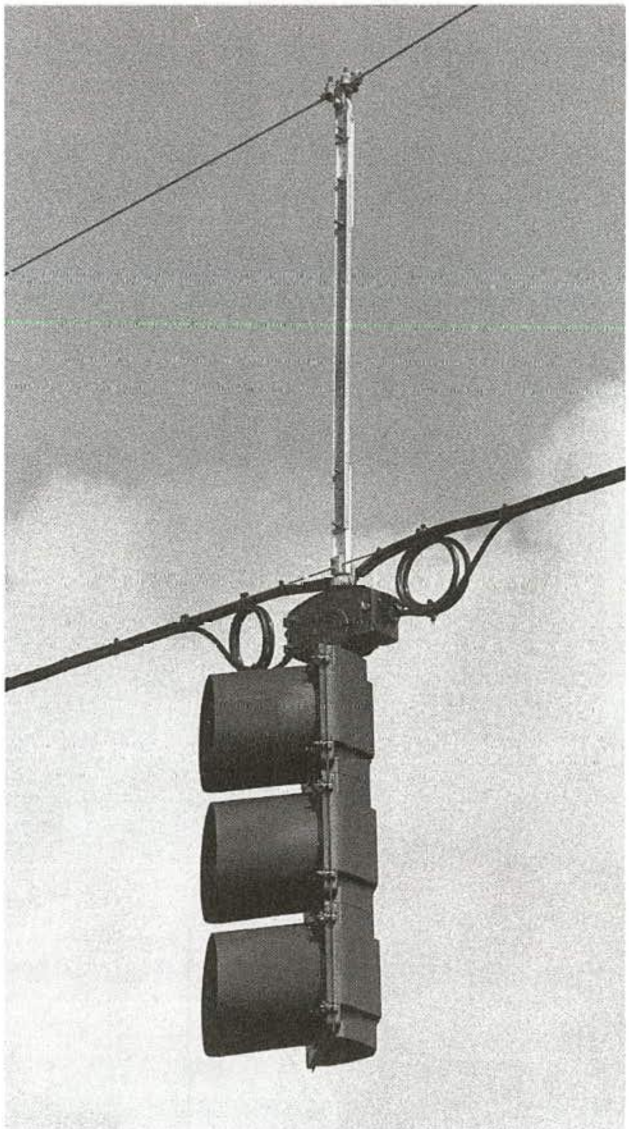


FIGURE 34 Disconnect hanger.

jurisdictions use only one cable to support all heads, others use two or three cables to support all heads, and some use a cable dedicated to each head. Electrical cables to the signal heads are secured to the supporting cables, using lashing rods, cable rings, or other similar devices.

Span-wire installations provide considerable flexibility in head placement. Although configurations are almost unlimited, the two most common designs are the diagonal span, in which two poles support a cable running diagonally across the intersection, and the box span, in which poles, located on each corner of the intersection, are connected together by a cable assembly to form a box. When a box span is desired, but the poles must be set back from the intersection for recovery purposes, a modified (or drop) box span can be used. A cable box, typically formed along the extensions of the four approach curb lines, is suspended by four diagonal cables leading back to the strain poles. Example configurations are shown in Figures 30 and 31.

Mast Arm Mounting Techniques

Mast arm assemblies are cantilevered structures designed to locate signal heads over the roadway. The arm assembly is attached to a vertical shaft; both components typically are made either of aluminum or steel tubular shapes.

Arm assemblies are available in a number of different designs. A monotube arm assembly (Figure 32) provides a clean, although sometimes overwhelming, appearance. A truss type of arm uses two cantilevered members, each of which is smaller than would be used in a monotube design. A trombone arm is a variation of the truss; the arm's structural members are parallel, and signal heads are mounted horizontally between the two members. Decorative and monolithic mast arm assemblies typically include rectangular cross sections and silhouettes, as shown in Figure 33.

Mast arm structures provide substantial rigidity for signal mountings but are limited in their adaptability to unusual or large intersections. A practical limit to arm length is in the range of 50 ft, although longer arms have been supplied. Some designs permit the temporary rotation of the arm out of its normal position, a benefit where overheight loads are occasionally encountered.

Most mast arm assemblies are used in a box configuration, where a pole and arm are located on each corner of the intersection. Some jurisdictions use a diagonal design, with two poles and arms pointing toward each other diagonally across the inter-

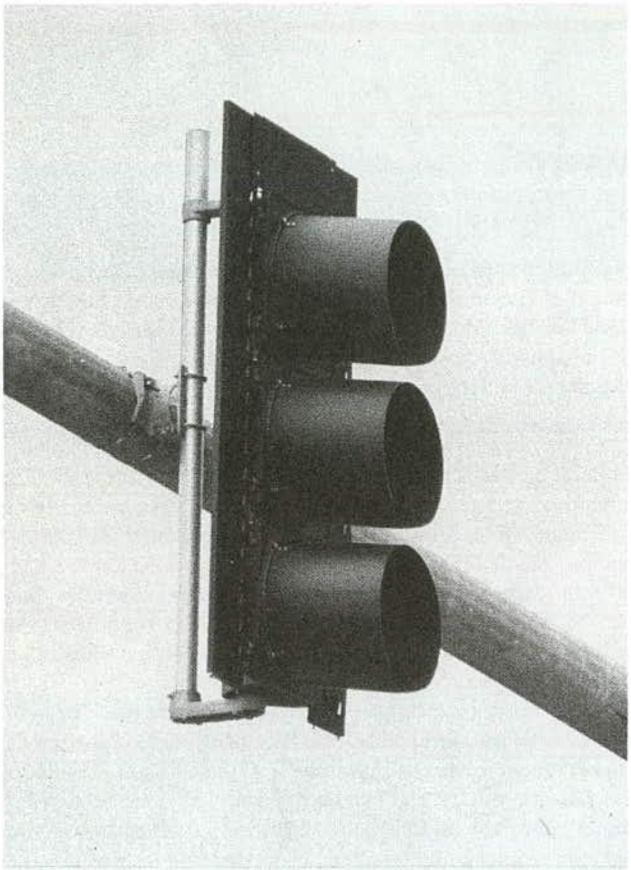


FIGURE 35 Signal mounting bracket.

section. Signal heads can either be rigidly mounted to the arm, or can be free-swinging below the arm. Rigidly mounted signals (particularly those with backplates) add considerable wind loading to the arm, an important concern in structure design.

Mounting Hardware

Signal mounting hardware, like the signal head itself, must be of a rugged, durable design. Various types of hardware are available to adapt standard signal heads to the different signal mounting techniques used across the United States.

Mounting hardware for span-wire installations varies widely by jurisdiction. A saddle clamp, or clevis, which rests on the supporting cable, is commonly used. Signal hangers are designed to attach to the clevis with a pin, and provide for a weatherhead cable entrance into the signal head.

Disconnect hangers (Figure 34) are terminal boxes made integral with the signal hanger. The disconnect hanger assembly is permanently mounted on the span wire. A terminal strip for attaching the signal feed wires is provided in the box, and a multipin plug and socket allows easy replacement of the signal head itself.

Mounting brackets for mast arm mounted signals provide two options—a free-swinging, below-the-arm mounting, or a rigid mounting. Free-swinging mountings are basically the same as span-wire fittings. Rigid mountings come in a number of different configurations. An elevator plumbizer is a tubular pipe extension, flattened out to attach, in line, between two sections of the signal head. It can either be used at the end of the mast arm, with the bracket coming out the side of the signal head, or at intermediate points along the arm, with the bracket extending directly behind the signal head. As the mounting creates a gap between sections, the technique frequently is used with backplates to minimize the visual discontinuity.

A number of different adjustable brackets, some of which are patented designs, are available for mast arm-mounting applications. These brackets, which typically support the signal head at both ends, as shown in Figure 35, permit full directional adjustment of the signal head on the arm. Special brackets are necessary for programmed visibility signals, because of the greater rear clearance required.

CHAPTER SIX

POWER FAILURE SAFEGUARD EQUIPMENT

Occasionally, the utility supplying electric power to the signals at an intersection will experience a power failure, resulting in darkened indications in the street. These power failures may be weather related—nearby lightning strikes, strong winds, and ice storms all create problems—or may be the result of a nearby accident knocking down distribution lines, or a failure at the generating station itself. During times of peak electrical demand, brownouts and blackouts may also be a problem.

Most states recognize the potential for such a signal failure, and include in their state traffic laws a requirement to treat malfunctioning signals as a four-way stop. There are two drawbacks to this approach: Many drivers ignore the requirement for the four-way stop, feeling that the "major road" has the right-of-way, and, during a nighttime power failure, it may be difficult for a driver to identify the presence of a darkened signalized intersection approached at normal driving speeds.

Where the dominance of one street over the intersecting street is immediately obvious to an approaching driver, the "major road right-of-way" assumption works reasonably well, much like the main-street yellow, side-street red flashing operation following the triggering of the conflict monitor. However, where both streets have similar characteristics, an incorrect assumption by a driver may have tragic consequences. Under congested conditions, a major intersection will alternate between movements only as bolder drivers pull in front of timid drivers. After a short wait, timid drivers usually become bolder drivers, and the movements reverse themselves.

The nighttime power failure provides for the greatest concern, because a motorist approaching at speed may not see the darkened signal heads or other indications of a major intersection until it is too late to stop. This is particularly critical where signal head bodies are dark (green, olive, or black), and where mast arm supports are not used.

BLACKOUT COUNTERMEASURES

There are several levels of countermeasures that have been used to protect the motorist from darkened signal indications. The level of protection provided appears to vary in direct proportion to the expense of the countermeasure; some countermeasures may not be cost-effective for the benefits provided.

The most protection for the most expense is the provision of a standby generator adjacent to the intersection controller. Typically powered by bottled LP gas, and using automotive-type batteries for ignition, the generator starts operation when the loss of electrical power is sensed. The generator continues to run, providing sufficient electrical energy to operate the intersection, until the fuel supply is exhausted.

Generator systems are high-maintenance items; they must be operated regularly to ensure prompt starting when an actual blackout occurs, and fuel supplies must be replenished frequently. They also may be unsuitable for urban areas, where noise and hot exhaust fumes could annoy passing pedestrians. A prime application for the generator backup system would be a major rural intersection, where long-term power failures have been a problem.

Shorter power failures can be protected against by an uninterruptable power supply (UPS) system, similar to those used on computer systems. Using batteries and an inverter to supply the 115 volts AC necessary to operate the controller and related equipment, these systems can operate an intersection for 10 to 30 min, depending on the number of batteries. Standby times can be increased considerably by transferring the intersection into a flashing mode, which darkens pedestrian signals and halves the on time of the vehicular indications.

One manufacturer has packaged a UPS system specifically for traffic signalization applications. The controller cabinet power supply is conditioned by the circuitry of the UPS unit, regulating the AC line voltage and eliminating transients and noise transmitted along the utility's lines. Upon loss of adequate line voltage, the unit instantly transfers to the battery-powered inverter, without interrupting the operation of the signals in the street (*19*).

The next lower step in protection is the use of battery-operated flashers activated by the loss of power to the intersection. One drawback of this type of protection is that frequently it does not meet the requirements of the MUTCD for the flashing operation of signals, in terms of number of indications, length of flash, and intensity of flash. Previous installations of this type used incandescent and neon tube light sources, which both were high-energy users with a disappointing light output level. Recent advances in strobe light technology may provide a better light source with a lower current draw.

Several agencies have been experimenting with folding signs, activated by the loss of electrical power. Most are motor-driven or solenoid controlled, so that the sign opens when power is lost, then automatically closes when power is restored. Using these signs, an intersection could be signed as a four-way stop when power to the signals has been interrupted. One limitation to these signs is their tendency to freeze shut during icy conditions.

Perhaps one of the least expensive approaches to the nighttime blackout problem is the identification of the intersection with reflective signing. Large overhead street name signs, mounted in a standard position adjacent to the vehicular signal indications, as shown in Figure 36, may help to identify the presence of a darkened intersection to approaching motorists.

In a similar approach, many European countries use backplates with a white reflective border on each signal face. The border helps provide added target value to the signals when they are operational, and also helps to identify the absence of the indications when they are off.

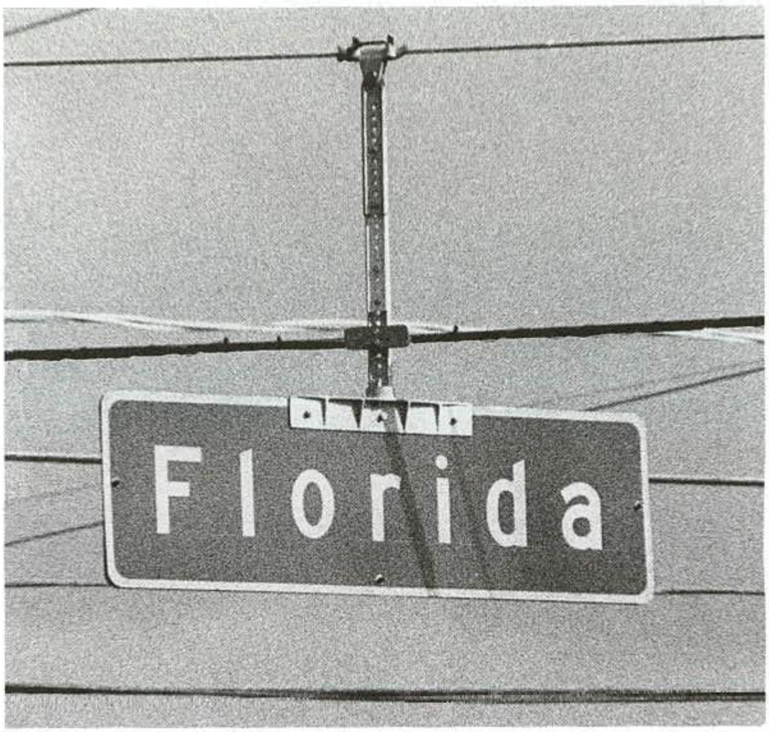


FIGURE 36 Overhead street name sign.

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APPENDIX A
SUMMARY OF PRACTICE SURVEY

As part of the preparation of this Synthesis, a survey of practice was undertaken. A four page survey questionnaire was developed and distributed by the Transportation Research Board. Forty-seven responses were received; 34 from state departments of transportation, and 13 from local or county transportation agencies. These responses represent almost 80,000 signalized intersections across the United States.

The survey was divided into five categories -- controller equipment, controller monitoring and failsafe equipment, detection equipment, systems, and displays and mountings. Responses to questions are summarized on the following pages.

CONTROLLER EQUIPMENT

How many signalized intersections are under your agency's jurisdiction?

	Local/County Agencies	State Agencies
High	1,116	8,000
Low	114	0
Average	387	2,243

Of these intersections, what is the current distribution of controller operations?

Signals are mostly:	Local/County Agencies	State Agencies
Pretimed	3	8
Semi-Actuated	4	7
Full-Actuated/Basic	4	10
Full-Actuated/V.D.	2	9

What is the average age of your existing controllers?

	Pretimed	Actuated
High	30 years	15 years
Low	2 years	3 years
Average	15 years	7 years

What is your distribution of pretimed controller equipment already in the field?

Signals are mostly:	Agencies
Electromechanical	26
Solid State Pretimed	8
NEMA Actuated/Recall	8
Type 170	1

What are you currently installing to provide pretimed operation?

Signals are mostly:	Agencies
Electromechanical	4
Solid State Pretimed	16
NEMA Actuated/Recall	20
Type 170/179	2

What is your distribution of actuated controller equipment already in the field?

Signals are mostly:	Agencies
Solid State Pretimed w/Actuation	2
NEMA	39
Type 170/179	6

What are you currently installing to provide actuated operation?

Signals are mostly:	Agencies
Solid State Pretimed w/Actuation	1
NEMA	39
Type 170/179	7

If you use controllers conforming to the NEMA Standards, do you permit:

Internal coordination?	45 Agencies Yes, 2 Agencies No.
Internal preemption?	46 Agencies Yes, 1 Agency No.
Keyboard entered overlap assignments?	41 Yes, 6 No.

CONTROLLER MONITORING AND FAILSAFE EQUIPMENT

Are all new controller assemblies required to have a conflict monitor?
All respondents indicated Yes.

Are conflict monitors with features beyond current standards (i.e., NEMA "Plus" or Model 210 "Plus" monitors) specified? If Yes, what features?
16 agencies - Yes
21 agencies - No.
Of the Yes respondents, a large majority require the full range of extras, including Green-Yellow, Green-Red, and Yellow-Red monitoring, and short yellow clearance protection.

Are you specifying current monitoring for the burned-out bulb protection not provided by standard conflict monitors?
Yes - 3 agencies
No - 42 agencies.

Are you specifying special power failure protection equipment, such as battery backup, battery operated flashers, automatic generators, solenoid operated fold-out signs, etc.?

Four agencies reported some attempts to cope with this problem. One uses battery operated flashers at critical locations, and another allows local maintaining agencies to install automatic starting generators at key locations. A third agency installs a battery operated modem to contact a closed loop type monitoring system and report the outage. The fourth agency installs signs to be manually unfolded during an extended power outage.

VEHICLE DETECTION EQUIPMENT

What type of vehicular detectors are you currently installing?

All respondents indicated that the inductive loop detector was their primary vehicle detector. Five respondents reported significant (over five percent of their total) numbers of magnetic detectors, and four reported similar quantities of magnetometer installations.

Are you satisfied with your current detector performance and reliability?

Responses were mixed, with the "Yes, but" reply being common. Problems noted appear to be related to the roadway loop installation, with pavement failure and poor initial installation posing the most problems.

How do you detect pedestrians?

Of those agencies that attempt to detect pedestrians (a large majority), all reported the pedestrian push button as being the detector of choice. One agency reported experimenting with the passive infrared detector for pedestrians.

How do you detect bicycles?

About half of the respondents indicate no attempt to treat bicycles different from pedestrians; i.e., only pedestrian push buttons are provided, and then only where needed. The remaining agencies are using various loop detector configurations at high usage locations, to provide the sensitivity necessary to detect bicycles.

The next five questions pertain to LOOP detectors:

How do you accomplish PRESENCE detection?

Long loops - 25 agencies
Small loops in series - 11 agencies
Use both - 11 agencies

If you use long loops, what configuration?

Rectangular and Quadrupole loops are the most popular.

What configuration of small loops do you use?

The square loop was most popular, with the diamond being a distant second choice.

Do you specify tubing encased loop detector wire?

A small majority of respondents reported that they specify tubing encased wire for at least some of their installations.

Do you utilize timing features on detectors?

Most agencies are using timing features for special locations.

INCORPORATION INTO SYSTEMS

Please distribute your controllers already in the field into the categories shown:

Isolated	- 50 percent
Time Base Coordinated	- 12 percent
Interconnected Time of Day	- 12 percent
Distributed Master/Closed Loop	- 9 percent
Traffic Responsive Arterial	- 9 percent
Central Computer Systems	- 8 percent

Please distribute interconnected signals by type of interconnect media: (In order of responses:)

1. Multiconductor signal wire
2. Twisted pair cable
3. Leased telephone lines
4. Agency owned coaxial cable
5. Leased CATV lines
6. Fiber optics.

Please distribute system controlled signals by low volume hour operation (late night, etc.)

Remain coordinated	- 17 agencies
Operate free	- 23 agencies
Flash	- 9 agencies

Do you permit remote downloading of controller timing data?

Coordination data	- 33 agencies
Phase related data	- 27 agencies

DISPLAYS AND MOUNTINGS

Please distribute existing signal installations into the categories shown:

Signals are mostly:	Local/County Agencies	State Agencies
Pole Mounted	1	1
Span Wire Mounted	3	18
Mast Arm Mounted	8	14

Indicate your current standards (as many as may apply):

	Agencies
Ball Lenses	
Glass Only	10
Polycarbonate Only	21

- Either Glass or Polycarbonate 15
- Arrow Lenses
  - Glass Only 15
  - Polycarbonate Only 17
  - Either Glass or Polycarbonate 14
- Reflectors
  - Alzac Aluminum Only 28
  - Mirrored Glass Only 1
  - Plated Plastic Only 2
  - Either Glass or Aluminum 9
- Signal Heads
  - Polycarbonate Only 11
  - Aluminum Only 11
  - Either Polycarbonate or Aluminum 25
- Signal Door Color
  - Yellow 23
  - Black 20
  - Green 5
- Signal Body Color
  - Yellow 31
  - Black 11
  - Green 7
- Pedestrian Signal Lenses
  - Word 22
  - Symbol 14
  - Either Word or Symbol 10
- Pedestrian Signal Illumination
  - Incandescent Allowed 43
  - Neon Allowed 8
  - Fiberoptic Allowed 8

Does your agency commonly use the following displays or indications:

- Red Arrows — 16 agencies yes; 31 agencies no.
- Yellow Arrows — 44 agencies yes; 3 agencies no.
- Dual-color (G-Y) arrows — 17 agencies yes; 30 no.
- Right turn overlaps — 30 agencies yes; 17 agencies no.

Do you dim signals at night? If yes, which colors?

Other than flashing beacons and programmed visibility signals, only three agencies occasionally dimmed signals. These agencies would dim any of the three vehicular indications and pedestrian movements.

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