Part III
SIGNALS

A—INTRODUCTION

Section 3A-1 Definitions

Highway traffic signals include all power-operated traffic control devices, except flashers, signs, and markings, by which traffic is warned or is directed to take some specific action. A glossary of traffic signal terms will be found in appendix A.

3A-2 Value of Signals

The traffic signal is a valuable device for the control and safe facilitation of vehicle and pedestrian traffic. Because of its predetermined or traffic-induced assignment of right-of-way to the various movements necessary at intersections and at other street and highway locations, the traffic signal exerts a profound influence on traffic flow. In most cases a signal installation will operate quite definitely to either the advantage or disadvantage of the vehicles and persons controlled. Consequently it is of the utmost importance that the selection and use of such an important control device be preceded by thorough study of roadway and traffic conditions by an experienced engineer. Equally urgent is the need for checking the efficiency of a traffic signal once in operation to ascertain the degree to which the type of installation and the timing program meet the requirements of traffic, and to permit intelligent operating adjustments to be made in the controls. Checkbacks are of value not only to the particular installation concerned but in the selection of proper equipment and operating plans for future installations as well.

Highway traffic signals, properly located and operated, usually have one or more of the following advantages:

1. They provide for orderly movement of traffic. Where proper physical layouts and control measures are used they can increase the traffic-handling capacity of the intersection.
2. They reduce the frequency of certain types of accidents.
3. Under conditions of favorable spacing, they can be coordinated to provide for continuous or nearly continuous movement of traffic at a definite speed along a given route.
4. They can be used to interrupt heavy traffic at intervals to permit other traffic, pedestrian or vehicular, to cross.

5. They represent a considerable economy, as compared with manual control, at intersections where the need for some definite means of assigning right-of-way first to one movement and then to another is indicated by the volumes of vehicular and pedestrian traffic, or by the occurrence of accidents.

There is a belief among many laymen and some engineers that traffic signals are the answer to all traffic problems at intersections. This has led to their installation at a large number of locations where no legitimate factual warrant exists. The erroneous attitudes that sometimes lead to unjustified installations of traffic control signals should be resisted.

To fill emergency needs there has been some use of portable types of traffic control signals. These devices have limited value and are difficult to standardize, particularly as to application and location. Drivers become accustomed to the presence or absence of standard traffic signal controls, and the introduction of a portable signal, even for a temporary period, may create hazard. The portable traffic signal is therefore not recognized in this Manual as a standard traffic control device.

Many standard traffic signal installations, even though warranted by traffic and roadway conditions, have been ill-designed, ineffectively placed, improperly operated, or poorly maintained. The typical consequences are excessive delay, disobedience to signal indications, use of less adequate alternate routes to avoid signals, and, often, increased accident frequency. Similar difficulties are found when signals are installed under conditions that do not satisfy the minimum warrants set forth in this Manual.

A careful analysis of capacity characteristics and other conditions at a large number of traffic signal installations, coupled with the judgment of engineers with long experience in the signal field, has provided a series of minimum warrants that define the conditions under which traffic signal installations may be justified. These warrants are presented in this Manual for several traffic signal classifications (secs. 3D–3 to 9; 3E–3, 4; 3F–2; 3G–3, 11, 16; 3H–3).

Separate warrants are given for rural and urban conditions in recognition of differences in the nature and environment of traffic in these two general classes. Drivers in rural areas are conditioned to relatively light traffic, and rural intersections with only moderately heavy traffic volumes have greater potentials in terms of congestion and hazard than do similar intersections within a city area where heavier volumes predominate.

3A–3 Standardization

Because of the increasing range of traffic circulation, it is of primary importance that there be national standardization of those features of traffic signals that affect public participation in traffic movement. Design, application, location, and operation lend themselves to a certain degree of standardization, and standards for such features are presented herein.

A driver or pedestrian must first see signals and then react to their indications. Location and sequence of operation are basic requirements. Signals should be placed where a driver (or pedestrian) cannot miss seeing them. Standard signal indications and sequences should be used universally so that a signal message can be recognized and heeded at a glance.

3A–4 Legal Authority

Traffic control signals should be installed and operated on public highways only by legally delegated or constituted public authority. The erection of signs or other devices that hide from view or interfere with the effectiveness of any traffic signal should be prohibited. It is imperative that traffic signal indications be strictly observed and enforced. Suitable legislative models covering these points are presented in the Uniform Vehicle Code (secs. 11–201 to 206) and in the Model Traffic Ordinance (secs. 4–1 to 9). The Code and the Ordinance direct the State highway commission and the city traffic engineer, or similar public officials or bodies, to place and maintain a uniform system of traffic control devices correlated with and, so far as possible, conforming to the system currently approved by the American Association of State Highway Officials. When this broad control is properly exercised, the full value of standardization in traffic signal design and installation can be realized.

3A–5 Classification

In the classification of traffic signals that follows, the distinction is made on the basis of operating function and not the traffic signal unit itself. It is common practice to use the term "signal" to describe the complete installation, and that practice will be followed in this manual.

Highway traffic signals are thus classified herein as follows:

1. Traffic control signals (Stop-and-Go):
   - (a) Pretimed signals (secs. 3D–1 to 25).
   - (b) Traffic-actuated signals (secs. 3E–1 to 29):
     - (1) Full traffic-actuated signals.
     - (2) Semi-traffic-actuated signals.
     - (3) Traffic-adjusted signals.
2. Pedestrian signals (secs. 3F–1 to 7).

3. Special traffic signals:
   (a) Flashing beacons (secs. 3G–2 to 7).
   (b) Lane-direction-control signals (secs. 3G–8 to 14).
   (c) Traffic signals at drawbridges (secs. 3G–15 to 19).
4. Train-approach signals and gates (secs. 3H–1 to 10).

B—FEATURES COMMON TO PRETIMED AND TRAFFIC-ACTUATED SIGNALS

Section 3B–1 General Aspects of Signals

The features of traffic control signals in which vehicle operators and pedestrians are interested, namely, the location, design, indications, and legal significance of the signals themselves, are identical in pretimed and traffic-actuated signals, the difference between the two being in the mechanisms by which they are operated. Standardization in those design factors that affect the traffic to be controlled is especially important. The sections immediately following contain all standards and requirements of this nature that are equally applicable to the types of signals named. Standards applicable to but one type, including design features and methods of operation, are presented in subsequent subdivisions.

3B–2 Design for Future Needs

Traffic control equipment should always be purchased with the future in mind. Flexibility that may not be considered immediately necessary will often be found desirable and economical within the life of the equipment.

Equipment that will give long effective life will almost always prove an economy even if the first cost is moderately higher than that of equipment of inferior quality.

3B–3 Number of Lenses per Signal Face

Each vehicular signal face shall have at least three lenses—red, yellow, and green—except where a green arrow lens is used alone to indicate continuous movement, or where signals are used as described in section 3B–22. It may have additional indications as listed herein.

The yellow indication serves the following important traffic control functions that cannot satisfactorily be served by a signal face having only red and green indications:

1. It acts as a transitional indication at the end of the green interval and warns approaching traffic of a pending change in the signal indication.

2. It acts as a clearance interval for traffic within an intersec-

tion or other signalized area as well as for those vehicles approaching so closely that to stop would be hazardous.

3. Flashing yellow is important as a caution signal when the signal is not being operated as a stop-and-go device.

In no case, however, should a traffic signal flash yellow for all traffic entering the intersection. Flashing operation should indicate yellow for the major street and red for all other legs of the intersection, or flashing red for all directions.

Green arrow indications shall be shown at intersections where signals for individual turning movements are provided. These include: (1) Straight-through arrow; (2) left-turn arrow; and (3) right-turn arrow.

Signals for the control of pedestrians may also be required (sec. 3F–2).

3B–4 Color and Position of Lenses

Lenses in a traffic signal face should preferably be arranged in a vertical line. **The red shall be at the top, the yellow immediately below, and the green at the bottom. Where a horizontal mounting is used, the red shall be at the left, the yellow next, and the green at the right.**

Green arrow lenses should normally be located as near as practicable to the movements they control, but **when more than one arrow is placed in the same vertical line, the straight-through arrow shall be below the circular green, if any, the left-turn arrow next, and the right-turn arrow at the bottom. With a horizontal mounting the left-turn arrow shall be to the immediate right of the yellow, the circular green, if used, shall be next, followed by the straight-through and right-turn arrows, respectively.**

Arrows as enumerated above may be placed at angles other than horizontal or vertical to indicate movement into streets which leave the intersection at various angles (sec. 3B–6).

Signals for control of pedestrians shall be adjustable separately from vehicular signal indications and assembled as specified in section 3F–6, and shall be rectangular in shape as specified in section 3F–4. The top indication shall be DONT WALK and the bottom indication shall be WALK.

The colors red, yellow, and green shall conform to the latest standards for adjustable-face traffic control signal heads of the Institute of Traffic Engineers (approved as an American Standard by the American Standards Association), in Institute of Traffic Engineers Technical Report No. 1.[11]

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[11] *Adjustable Face Traffic Control Signal Head Standards*, Technical Report No. 1. Revised 1958, Institute of Traffic Engineers, 2029 K Street, N.W., Washington 6, D.C.

3B-5 Meaning and Application of Color and Arrow Indications

Color and arrow indications in traffic control signals should have the meaning ascribed to them in the Uniform Vehicle Code and no other meanings. In no case, however, should a driver be permitted to enter or proceed through an intersection without due regard for the safety of other persons within the intersection regardless of signal indications.

Satisfactory results from traffic signal operation require a uniform understanding of their color indications. Those herein set forth are in general accord with the Uniform Vehicle Code (secs. 11-202 to 204). **Combinations of signal colors (green with yellow, yellow with red, or green with red) shall not be displayed simultaneously except where green turn arrows are shown together with steady yellow or steady red under those conditions described below.**

This section applies primarily to traffic control signals at intersections, but appropriate interpretation is to be made for use of signals elsewhere.

The intended meanings of the signal indications are as follows:

Circular green (alone):

1. Vehicular traffic facing the signal may proceed straight through or turn right or left unless a sign, reflectorized or preferably illuminated, at such place prohibits either such turn. However, vehicular traffic, including vehicles turning right or left, shall yield the right-of-way to other vehicles and to pedestrians lawfully within the intersection or an adjacent crosswalk at the time such signal is exhibited.

2. Pedestrians facing such signal may proceed across the roadway within any marked or unmarked crosswalk unless directed otherwise by a pedestrian signal.

Steady yellow:

1. Vehicular traffic facing the signal is thereby warned that the red indication will be exhibited immediately thereafter, or that the related green movement is being terminated.

2. Unless otherwise directed by a pedestrian signal, pedestrians facing such signal are thereby advised that there is insufficient time to cross the roadway.

The yellow signal shall not be shown simultaneously with the green or red indication except in the case of an arrow indication which is to allow a particular movement to continue when others in that direction are being stopped.

The yellow lens is required in standard signal apparatus for the reasons indicated in section 3B-3. Confusion has frequently arisen from the misuse of this lens. When the length of the yellow vehicle-clearance interval is correct, and the standard meaning above described is generally observed, necessary functions of warning and clearing the intersection are performed by this interval.

The configuration or dimensions of an intersection, or some physical condition such as high approach speeds, steep hills, or heavy truck traffic, may require a longer than normal clearance interval. In such cases the standard length of the steady yellow interval should be used in the first part of the clearance interval, followed by all-red indications during the second part of the clearance interval.

No circular green or green arrow indication or flashing yellow "caution" indication shall be terminated and immediately followed by a steady red or flashing red indication without the display of the steady yellow clearance interval; however, transition may be made directly from circular green or green arrow indication to flashing yellow indication. **The steady yellow indication shall not be used in any transition from steady red or flashing red indication to circular green, green arrow, or flashing yellow indication.**

Steady red (alone):

1. Vehicular traffic facing the signal shall stop before entering the crosswalk on the near side of the intersection or, if none, then before entering the intersection, and shall remain standing until the green indication is shown.

2. No pedestrian facing such signal shall enter the roadway unless he can do so safely and without interfering with any vehicular traffic, or unless a separate WALK indication is shown.

Green straight-through arrow (alone):

1. Vehicular traffic facing the signal may proceed straight through, but shall not turn right or left. Such vehicular traffic shall yield the right-of-way to other vehicles and to pedestrians legally within the intersection at the time such signal is exhibited.

2. Pedestrians facing the signal may proceed across the roadway within the appropriate marked or unmarked crosswalk unless directed otherwise by a pedestrian signal.

Green turn arrow (alone or with circular green, with steady yellow, with steady red, or with green straight-through arrow):

1. Vehicular traffic facing the signal shall comply with the meaning of the circular green, steady yellow, steady red, or green straight-through arrow indication as if it were shown alone, except that such vehicular traffic may cautiously enter the intersection to make the movement indicated by the green turn arrow. Vehicular traffic shall yield the right-of-way to pedestrians law-

fully within a crosswalk and to other traffic lawfully using the intersection.

2. Pedestrians facing such signal shall comply with the meaning of the circular green, steady yellow, steady red, or straight-through arrow indication as if it were shown alone, unless directed otherwise by a pedestrian indication.

Permitting vehicle operators to make right or left turns during the showing of the red signal without a modifying arrow or sign is not recommended. If turn arrows are shown when through movement is stopped, they should always be illuminated in conjunction with the red signal they modify. Shown alone (except at T intersections where through movement is impossible or over a separate turning lane where continuous movement can be accommodated), they create doubt as to whether further movements are forbidden during the indicated interval. Furthermore, drivers approaching an arrow indication may mistake it for the circular green indication.

The utility of arrow indications depends considerably upon there being a lane available for the movement indicated. Such lanes should be clearly marked at all times.

A circular green indication shall be given only when it is intended to permit traffic in each lane approaching the signal to proceed in any direction which is lawful and practical for traffic in those lanes. This is not intended to prevent prohibition of turns, at all times or during certain periods of the day, by the erection of signs. **When it is intended to permit traffic on a certain lane to make a certain turn or turns and prohibit it from proceeding straight through, the regular circular red lens facing that traffic shall be illuminated together with a green arrow for each permitted turn. Whenever it is intended to permit traffic on a certain thoroughfare or in a certain lane to proceed straight through and prohibit it from making a certain turn or turns, a green arrow for each permitted movement shall be illuminated, and the red lens facing that traffic shall not be illuminated.**

Except as noted below, each green arrow indication shall be followed by a steady yellow clearance interval to allow the traffic controlled by the arrow to clear the intersection. The yellow indication should be shown following the circular green indication, but should not be displayed in any signal face following a green turn arrow if the related turning movement is permitted to continue by a following or continuing display of a circular green indication in the same signal face.

In those cases where a turning movement is to be cut off while the straight-through movement continues, a separate signal face shall be provided to control the turning movement (fig. 3–3). It

shall be equipped with circular red and yellow lenses and a green turn arrow lens. When the turn is to be cut off, a yellow clearance interval shall be shown, followed by a steady red indication. The purpose of such a signal face should be made clear by its location and by a sign located close to the signal and having an appropriate message, such as LEFT TURN SIGNAL or RIGHT TURN SIGNAL.

Flashing red (Stop signal):

When a red lens is illuminated by intermittent flashes (50–60 per minute), drivers of vehicles shall stop before entering the nearest crosswalk at an intersection or at a Stop line when marked, and the right to proceed shall be subject to the rules applicable after making a stop at a Stop sign. Stop signs should not be used at signalized intersections even though the traffic signals may be on flashing red for part of the day or at irregular intervals.

Flashing yellow (caution signal):

When a yellow lens is illuminated with intermittent flashes (50–60 per minute), drivers of vehicles may proceed through the intersection or past such signal with more than ordinary caution.

Steady yellow shall not be used as a caution signal.

3B–6 Vehicular Signal Lenses

The optical unit of a signal consists of a lens, reflector, lamp and lamp socket. The lens is that part of the unit which redirects to the desired area the light from the lamp and its reflector.

All vehicular signal lenses shall be circular in shape, except that green arrow lenses may be rectangular. There shall be two approved sizes for circular lenses, 8 inches and 12 inches nominal diameter (fig. 3–1).

The 8-inch nominal diameter lens shall have a visible diameter of not less than 7¾ inches and an overall diameter of not less than 8⅜ inches. In the past, this has been the only standard size and is therefore the one in most common use.

The 12-inch nominal diameter lens shall have a visible diameter of not less than 11½ inches and an overall diameter of not less than 12-1/32 inches. Experience with this size of lens has been relatively limited, but is sufficiently successful to justify its acceptance, at least for locations where greater signal conspicuousness is needed. The 12-inch red lens is often used with the smaller size yellow and green lenses to give special emphasis to the most restrictive indication. However, all three lenses may be the larger size. The 12-inch lens provides an important increase in the target value of the signal at locations where signal indications tend to be overlooked. Among the situations where 12-inch lenses have been applied are:

1. Rural intersections or those with high approach speeds.
2. Isolated intersections or those where signalization might be unexpected, such as the first signal beyond a freeway exit.
3. Special problem locations such as those with conflicting or competing background lighting.
4. Intersections where drivers view both traffic control and lane-direction-control signals simultaneously.

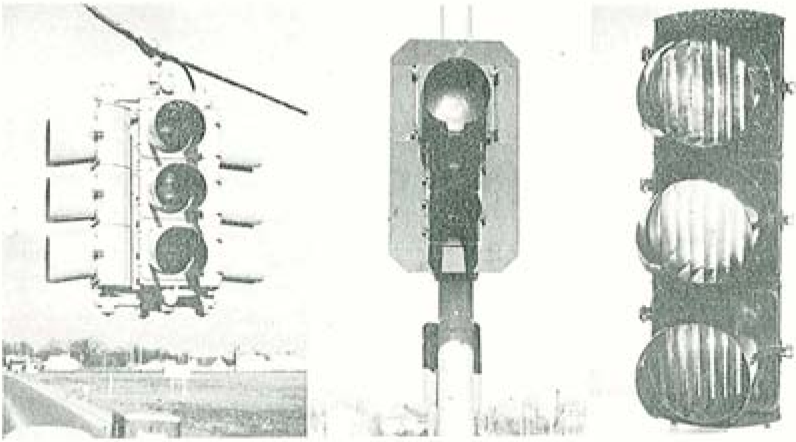

Figure 3–1. Typical signal features: Left, overhead span-wire mounted signal with standard 8-inch lenses, shielded by visors; center, post-mounted signal with a 12-inch red lens, shielded by visors and backplate; right, signal lenses shielded by visors with louvers.

For use in directing vehicular traffic, green arrows shall point out the approximate direction in which movement is permitted. The arrow shall be pointed vertically upward to indicate a straight-through movement, in a horizontal direction to indicate an approximate right-angle turn, and obliquely on an upward slope approximately equal to the angle of the turn when it is substantially different from a right angle.

It is essential that approaching drivers be able to recognize the green arrow shape at a distance of at least 200 feet from the signal.

Each arrow lens shall show only one arrow direction. Double-headed arrows are not acceptable. **The arrow shall be the only illuminated part of the lens. It shall be reproduced on the lens in conformance with the appropriate dimensions and shape for either the 8-inch or 12-inch lens as shown in figure 3–2. All**

lenses shall conform to the latest standards for traffic control signal heads of the Institute of Traffic Engineers.[12]

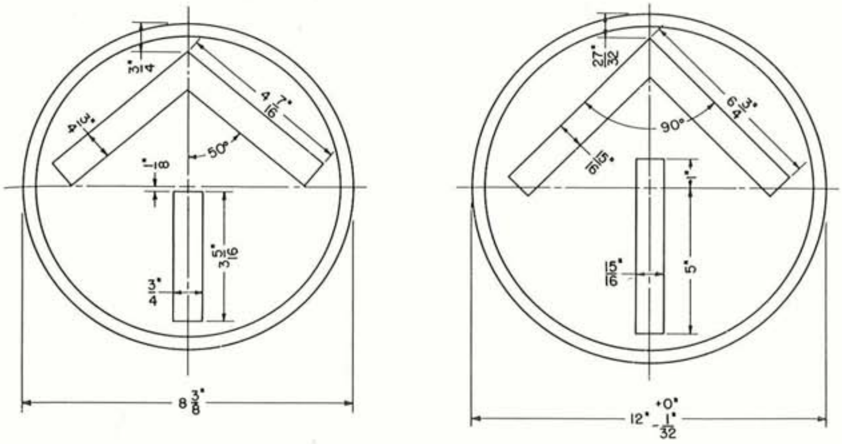

Figure 3–2. Standard arrows for signal lenses (Institute of Traffic Engineers).

3B–7 Lettering on Lenses

Lettering shall in no case be used on the visible part of vehicular signal lenses. The practice of embossing words such as GO and STOP on vehicular signal lenses reduces their effectiveness and is no longer prescribed in the standards for traffic control signal heads.

3B–8 Illumination of Lens

Each lens shall be illuminated independently. This is essential to permit uniform position of lenses, to give satisfactory brilliance, and to provide the necessary flexibility in signal indications. Candlepower charts showing the required distribution of light from each vehicular signal optical unit, and standards for lamp performance, are included in the Institute of Traffic Engineers Technical Report No. 1, cited above in section 3B–6.

3B–9 Visibility and Shielding of Lens

When a vehicular traffic signal lens is illuminated and the view of such an indication is not otherwise physically obstructed, it shall be clearly visible to drivers it controls at distances up to 1,000 feet under all atmospheric conditions except dense fog.

Each signal face shall be so adjusted that its beams will be of

[12] *Adjustable Face Traffic Control Signal Head Standards*, Technical Report No. 1. Revised 1958, Institute of Traffic Engineers, 2029 K Street, N.W., Washington 6, D.C.

maximum effectiveness to the approaching traffic for which it is intended. Visors, louvers and back-plates often improve a signal's effectiveness (fig. 3–1).

In general, vehicular signals should be so aimed as to have the maximum effectiveness for approaching drivers at a distance from the Stop line equal to the average distance they would travel while reacting to the Stop indication and stopping their vehicles from a normal operating speed. The influence of curves, grades, and obstructions should be considered in the directing and location of signals.

Irregular street design frequently necessitates placing signals for different street approaches so that there is a comparatively small angle between their beams. **In these cases, each signal face shall, to the extent practicable, be so shielded by visors or louvers that an approaching driver can see only the indication intended for him to obey.**

The foregoing does not preclude special aiming of certain lenses so that the driver does not see their indications within the stated ranges of distance if other indications must first be observed and simultaneous viewing of both signal indications could cause the driver to be misdirected.

3B–10 Auxiliary Signs

When auxiliary signs are needed, they shall be reflectorized or preferably illuminated and shall be attached in a suitable position adjacent to the signal assembly (fig. 3–3). Signal heads and auxiliary signs shall be mounted so that the minimum clearances of the total assembly will conform to the provisions of section 3B–13.

Where used in conjunction with traffic signals, illuminated signs should be designed and mounted in such manner as to avoid undesirable glare and reflections in any combination of the signal and sign assemblies. The traffic control signal must be given dominant position and brightness to assure its target priority in the overall display.

3B–11 Types of Mounting for Signal Heads

Types of signal-head mountings include the following:

1. Alongside the roadway:
   - (a) Posts 8 to 15 feet high.
   - (b) Short brackets attached to poles (at same heights).
2. Over or in the roadway:
   - (a) Long brackets or mast arms extending from poles off the roadway.
   - (b) Cable suspension.
   - (c) Posts or pedestals on islands.

Mounting fixtures shall be so designed that horizontal and vertical adjustments are possible through a reasonable angle.

3B–12 Number of Signal Faces

There shall be a minimum of two vehicular signal faces visible to traffic on each approach to a signalized intersection. These shall be supplemented by pedestrian signals, where warranted, located at each end of each controlled crosswalk (sec. 3F–2).

Two (or more) properly located faces will in almost all cases provide drivers with a signal indication even though trucks or buses may momentarily obscure one signal face. Multiple faces provide a safety factor where the signals must compete with a brilliant background such as advertising signs or the sun. The occasional inevitable lamp failure in one face will not leave an approach without any signal indication.

The number of signal faces in excess of two per approach will be dictated by local conditions such as number of vehicular lanes, the need for special turn indications, and the configuration of the intersection and channelizing islands.

3B–13 Location of Signal Faces

The location of signal faces for each direction of approaching traffic shall be as follows:

1. Where all signal faces are post- or pedestal-mounted there shall be at least two on the far side of the intersection.

2. Where there is only one post- or pedestal-mounted signal face, it shall be on the far side, and there shall also be a mast-arm or span-wire mounted signal face for that approach.

3. Where visibility or other conditions require more than one span-wire or mast-arm signal, at least one of the overhead signal faces shall be in line with the approach it controls.

Signal faces shall be located so as to give drivers and pedestrians a clear and unmistakable indication of the right-of-way assignment from their normal positions on the approaches and as they enter or pass through the intersection area. Where pedestrian signals are installed they should conform to the location standards prescribed in section 3F–6. Where separate pedestrian signals are not installed, the vehicular traffic control signals should be located so as to assist pedestrians in determining when it is safe to cross.

Overhead signals are desirable at locations where signals at the side of the roadway are likely to be overlooked, as at isolated rural intersections, or where high-speed routes enter built-up areas, or where advertising signs and other distracting lights interfere with visibility of signals mounted along the roadway. Overhead signals have little value for pedestrian traffic, and post-

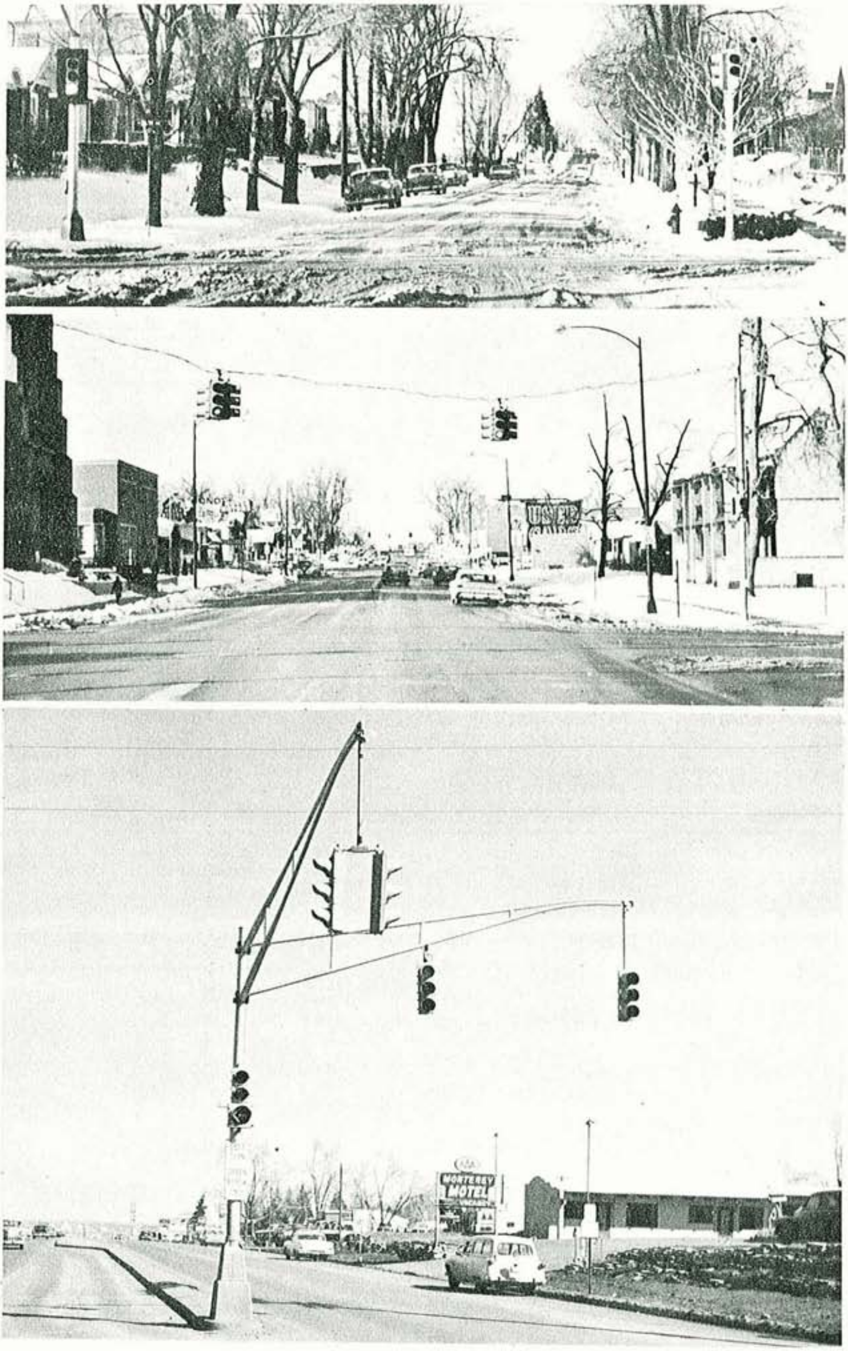

Figure 3–3. Typical traffic signal installations:* Top, *post or pedestal mounted.* Center, *span-wire mounted.* Bottom, *mast-arm mounted; note separate left turn signal and sign, and 12-inch arrow lens.

mounted signals are commonly used to supplement overhead installations where pedestrian control is important.

Where signals are suspended over the roadway, at least one face of the overhead installation facing each direction of travel should be located so that it will be clearly visible from where vehicles are brought to a stop.

Signals on posts or pedestals located within the roadway should be on properly designed islands and protected by signs and by night illumination.

Figure 3–3 illustrates typical practice for traffic signal mounting.

Where physical conditions prevent a vehicle driver from having a continuous view of at least one signal indication for approximately 10 seconds before reaching the stop line, an auxiliary signal shall be used to provide this visibility. If physical conditions make this impossible, a flashing yellow beacon (sec. 3G–5) or Signal Ahead sign (sec. 1C–16) shall be erected in a suitable position to warn approaching traffic. A flashing yellow beacon utilized in this manner may be interconnected with the intersection signal controller in such manner as to flash yellow during the period when drivers passing this beacon, at the legal speed for the roadway, will encounter a red signal upon arrival at the intersection.

3B–14 Height of Vehicular Signal Faces

The bottom of the housing of a post-mounted signal face shall not be less than 8 feet or more than 15 feet above the sidewalk, or, if none, above the pavement grade of the center of the highway.

The bottom of the housing of signal faces suspended over roadways shall not be less than 15 feet or more than 17 feet above the pavement grade of the center of the roadway.

Maximum visibility and adequate clearance should be the guiding consideration in deciding signal height. Grades on approaching streets may be important factors, however, in determining the most appropriate height.

3B–15 Transverse Location of Signal Faces

Signal faces mounted at the side of a street with curbs or an established curb line shall be located as near as practicable to that curb line, normally with a 2-foot clearance. In the case of nearside locations, they should also be located as near as practicable to the Stop line, or to where the Stop line would normally be. For the protection of the equipment from damage by passing vehicles, it is not desirable that any part of the signal head extend within 2 feet of the curb line. A signal or its support should not obstruct the crosswalk.

Where there is no curb, a signal face mounted at the roadside shall be not more than 10 feet off the edge of pavement or traveled surface, provided that it does not obstruct free use of the shoulder.

A signal face mounted on a span wire or mast arm provides a prominent indication and should be located as near as practicable to the line of the driver's normal view. An auxiliary signal face, either overhead or at the side, should be positioned transversely to give an effective dual indication and to fit the needs at the intersection. Where a signal face controls a specific lane or lanes of the approach, its transverse position should be unmistakably in line with the path of that movement.

3B–16 Limit of Signal-Controlled Area

A signal shall control traffic only at the intersection where the installation is located.

Depending on signals at a few intersections to control traffic at intermediate nonsignalized intersections is uncertain and hazardous. Under such conditions, drivers on cross streets at nonsignalized intersections must often enter the crosswalk to see a signal indication on the main street. Strangers are likely to enter nonsignalized intersections unknowingly, which is obviously hazardous.

3B–17 Removal of Confusing Advertising Lights

The Uniform Vehicle Code (Sec. 11–205) prohibits the display of any unauthorized sign, signal, marking, or device which interferes with the effectiveness of any official traffic control device. The enactment of this provision is particularly important. If enforced it will, among other things, reduce the serious confusion caused by lights similar to traffic control signals in color and location. The steps necessary to eliminate this sort of hazard are warranted.

3B–18 Roadway Widening to Improve Signalization

Widening of both the main highway and the intersecting roadway may be warranted to reduce the delays caused by assignment of right-of-way at intersections controlled by traffic signals. Widening of the intersecting roadway is often beneficial to operation on the main highway because it reduces the signal time that must be assigned to side-street traffic. In urban areas the effect of widening can be achieved by elimination of parking at intersectional approaches.

Additional width may be necessary on the leaving side of the intersection as well as the approach side in order to clear traffic through the intersection effectively.

3B–19 Provision for Future Installation

When future traffic needs, or physical changes in intersection design, can be foreseen, provision for these should be made in planning for signalization to minimize material and labor costs. This is illustrated by the following examples:

If future land development is likely to create justification for a pedestrian signal, the controller should be equipped with extra circuits to provide for future pedestrian intervals.

If a street is to be widened or an intersection is to be reconstructed in the predictable future, either a temporary signal installation or an installation to conform to the proposed final layout should be considered.

If future interconnection or vehicular turning intervals can be predicted, provisions for these should be incorporated in the controller.

3B–20 Signal Cable

The reliable and economical operation of a signal system is as dependent upon its cables or other means of interconnection as upon the other signal equipment. The International Municipal Signal Association Specifications for Wire and Cable are recommended as a guide for procurement of signal cable.[13]

3B–21 Efficiency and Continuity of Operation

The full utility of traffic signals is realized only when they are operated in accordance with actual traffic requirements. Inconvenience, disobedience, and hazard follow unnecessary, arbitrary, or inaccurate operation. The operating standards contained in this Manual provide for a reasonable efficiency in the operation of signals at warranted locations.

It is desirable that a person approaching a traffic signal should presume it is functioning unless he is given a conspicuous and specific indication to the contrary. Hence it is required that all signals in use be "live." When not operating as a stop-and-go device, the signal should be operated as a flashing device (secs. 3D–3, 3E–27).

Prior to placing signals in service and during seasonal shutdowns, when it is not desirable to operate the signals, they should be hooded, turned, or taken down so persons will be under no misapprehension that a lamp may be burned out.

3B–22 Unexpected Conflicts During Green Interval

No movement that may involve an unexpected crossing of

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[13] *Specifications for Municipal Communication Control, Signal and Power Cables.* International Municipal Signal Association, 130 West 42d Street, New York 36, N.Y.

pathways of moving traffic should be permitted during any green interval, except under unusual conditions when:

1. The movement involves only slight hazard;

2. Serious traffic delays are materially reduced by permitting the conflicting movement; and

3. Drivers and pedestrians subjected to the unexpected conflict are effectively warned thereof.

When such conditions of possible unexpected conflict exist, warning may be given by a sign or, under certain conditions, by the use of a flashing yellow or red signal instead of a green signal. The foregoing applies to vehicle-pedestrian conflicts as well as to vehicle-vehicle conflicts.

3B–23 Vehicle-Clearance Interval

A yellow vehicle-clearance interval shall be used following each green interval and, where applicable, after each green arrow interval. In no case shall a yellow interval be displayed in conjunction with the change from red to green. In order to avoid doing so, the use of separate signal faces is recommended when traffic movements are controlled by green arrows (sec. 3B–5, Green Turn Arrow).

The functions of the yellow interval should be exclusively to warn traffic of an impending change in the right-of-way assignment and to permit clearance of the intersection.

In general, the vehicle-clearance interval should be not less than 3 seconds nor more than 5 seconds in length. While clearance intervals longer than 5 seconds may occasionally be necessary at very wide intersections or under other unusual conditions, they are likely to cause impatience among drivers awaiting the signal change and consequent starting before the green indication appears. Under such conditions it has been found more satisfactory to supplement the normal yellow period with a short all-way red interval of sufficient duration immediately after the yellow period to permit the intersection to clear before cross traffic is released (sec. 3B–5).

3B–24 Flashing Operation of Traffic Control Signals

Flashing operation of a standard traffic control signal involves intermittent illumination of the red or yellow lens in each face. Traffic control signals are placed in flashing operation under the conditions prescribed in sections 3D–3 and 3E–27. The meaning of flashing yellow and flashing red is described in section 3B–5.

When signals normally operated as stop-and-go signals are put on flashing operation, the color indications given to the several streets should be based on the following considerations:

1. If one of the streets involved is a through street, it should be given a flashing yellow (caution) indication and the other approaches should be given a flashing red (stop) indication.

2. If the safe approach speed on one street differs from the safe approach speed on the other street or streets, the street having the higher safe approach speed should be given the flashing yellow (caution) indication and other approaches should be given a flashing red (stop) indication.

3. If safe approach speeds and traffic volumes on both streets are comparable or not significantly different, the traffic signal may be operated as flashing red for both streets.

The control of flashing operation of standard signals should be provided by an electrical mechanism supplementary to the signal timer. The signal timer should be removable without affecting the flashing operation. The mechanism operates in a manner similar to that of a flashing beacon (sec. 3G–2) to provide intermittent illumination of selected signal lenses. **The illuminating element in a flashing signal shall be flashed continuously at a rate of not less than 50 nor more than 60 times per minute. The illuminated period of each flash shall be not less than half and not more than two-thirds of the total flash cycle.**

In every case the change from flashing to stop-and-go operation should be made at the beginning of the common main-street green interval (i.e., when a common green indication is shown in both directions on the main street), and no change from flashing yellow to steady red is permissible without an intervening steady yellow. If, when in flashing operation, the signals flash yellow on the main street, the change from stop-and-go to flashing operation should be made during the common main-street green period; and if, when in flashing operation, the signals flash red on the main street, the change from stop-and-go to flashing operation should be made immediately following the main-street clearance interval.

3B–25 Traffic Signals Near Grade Crossings

At some street and highway intersections, railroad tracks pass within or near the intersection area, and the grade crossing thus formed is protected by train-approach signals (secs. 3H–1 to 9). At such intersections it is essential that the control of the street traffic signal be preempted from the signal controller upon approach of trains to avoid conflicting aspects of the traffic signal and train-approach signal. Such an arrangement requires a closed electrical circuit between the control relay of the train-approach signals and the preemptor in order to establish and maintain the preempted condition during the time that train-approach signals are in operation.

Traffic signals shall not be used in lieu of railroad grade crossing protection devices. There are, however, some crossings where train movements are regulated to the extent that train-approach signals are not required. In such cases preemption at the adjacent signalized intersections may be desirable to permit nonconflicting highway traffic to proceed during the time the crossing is blocked by a train. Except under unusual circumstances the interconnection should be limited to the traffic signals within 200 feet of the crossing.

There is a great diversity of configuration of intersection patterns involving railroad tracks. At some locations one or more tracks directly traverse the intersection area. At other locations the trackage cuts across one or more approaches. There are all degrees and combinations of vehicle volume, train frequencies, and waiting times.

There is, however, one fundamental requirement which must be observed in all cases. **The preemption sequence initiated when the train first enters the approach circuit shall at once bring into effect a signal display which will permit all vehicles to clear the tracks before the train reaches the intersection.**

To increase the safety factor at the railroad crossing, the normal sequence (no trains involved) of the traffic signals should be so designed that vehicles are not required to stop on the tracks even though in some cases this will increase the waiting time.

The exact nature of the signal display and location of the signals to accomplish this will depend on the physical relationship of the trackage to the intersection area. It is imperative, however, that the first stage of the preemption sequence be designed to clear vehicles from the tracks.

At the completion of the first stage of the preemption sequence, a second stage will come into effect which will persist until the preemption signal from the railroad control circuit ceases. The nature of this stage will depend upon the geometrics of the intersection and the nature and importance of the traffic flow, but will in all cases prohibit movements over the tracks. This stage may be steady red or flashing red. It may permit by arrow indications certain vehicle movements which do not cross over the tracks, and there may even be some transfer of nonconflicting rights-of-way during the preemption period. Naturally the probable duration of this period is a factor in all of the above.

When the train clears the crossing it is necessary to return the signal to a designated phase, this being the final stage of the preemption sequence.

When the green indication is preempted by train operation, a yellow clearance interval must be inserted in the signal sequence in the interests of safety and smoothness. To avoid misinterpretation during the time that the clear-out signals are green, consideration should be given to the use of 12-inch red lenses in the signals which govern movement over the tracks (sec. 3B–6).

Careful consideration needs to be given the control of all intersections involving train movements. The plan for signal control must be based on the specific factors that prevail at each intersection involved. The preemption equipment tends to be special for each case and frequently of considerable complexity.

3B–26 One-Way Restricted Zone Control

Control equipment is available for use at a narrow passage, such as a bridge, tunnel, or construction area, which is not wide enough to allow traffic to flow in opposite directions simultaneously. This operates essentially as a two-phase control, each approach being one phase, with an all-red clearance period added to the normal cycle. Traffic moves in one direction on one phase and in the opposite direction on the other phase. Between these movements the all-red interval provides time for clearance of such traffic as may be in the restricted area.

3B–27 Emergency and Civil Defense Operation of Traffic signals

Traffic signals operated under emergency conditions shall use color sequences with which drivers and pedestrians are familiar. Nonstandard colors, unusual flashing cycles, or flashing of yellow lights in signal assemblies while regular traffic signal operation goes on in the same assembly are to be avoided. This does not preclude, and in some cases will necessitate, the use of auxiliary indications independent of the traffic signal assembly to indicate the existence of an emergency condition.

Devices used on emergency vehicles to preempt (by radio) intersectional traffic signal control shall operate at a range sufficient to permit a normal clearance interval to take place in the change from green to yellow to red (or flashing red) before arrival of the emergency vehicle at the preempted location. Systems in which intersectional traffic signal control is preempted by emergency vehicles shall be designed and installed so as to provide a fail-safe indication to the driver of any emergency vehicle approaching an intersection whose equipment fails to preempt the traffic signal at that intersection. This fail-safe indication shall be given whether the failure results from a prior preemption by an emergency vehicle on the cross street, from equipment malfunction, or from any other cause.

Traffic signals operating in congested areas during emergency or civil defense conditions shall, as far as possible, be operated in a manner designed to keep traffic moving. Prolonged all-red or flashing signal sequences are to be avoided because of confusion, hazard, and delays caused by stoppage of traffic movement.

3B–28 Adequacy of Maintenance

Much of the authority and respect that traffic signals have may be traced to their clear-cut compelling indications. Signals with impaired efficiency cannot be expected to command the necessary degree of respect. Proper maintenance is, therefore, of primary importance from this functional viewpoint, and will pay other dividends in increasing the effective life of the signal equipment.

Maintenance should be an important consideration in the design and purchase of traffic signal equipment. If low first cost is followed by high maintenance costs or by serious losses of efficiency, it is obviously poor economy.

The standards set forth in sections 3B–29 to 3B–33 are intended to provide the essential features for an adequate maintenance program.

3B–29 Signal Lamp Replacement

Burned-out lamps convert traffic signals to the role of a traffic hazard. Immediate replacement of such lamps, and scheduled group replacement of lamps short of their anticipated life, are extremely important maintenance functions. The use of two signal faces for each approach roadway is an important factor in providing safety when a signal lamp burns out unexpectedly.

Remoteness of signals from maintenance facilities often entails delay in replacement of burned-out lamps. In maintenance jurisdictions having remote signals a regular lamp-replacement schedule is advised. Such a schedule should provide for replacement slightly short of the lamp-life expectancy as determined from consideration of the following factors:

1. Probabilities of lamp failure as applied to mass production and manufacturers' rating.

2. The effect on lamp life of the difference between the voltage at the lamp socket and the rated voltage.

3. The failure or reduction of lamp-life expectancy due to vibration in normal operation and as a result of lamp handling.

Actual hours of illumination for lamps vary according to lens position and timing schedules. For example, major-street green and minor-street red will require replacement more often than minor-street green and major-street red. These latter in turn will require replacement more often than the yellow.

3B-30 Cleaning

The reduction in brilliancy of a signal indication resulting from even a moderate amount of dust and dirt is generally very much underestimated. Signal lenses, reflectors, and lamps should be thoroughly cleaned at least once every 6 months. Lenses and reflectors should always be cleaned when lamps are replaced, unless the last regular cleaning has been very recent.

The frequency with which cleaning is required will vary according to the location of the signal. Signals located in industrial or other areas where the air is dusty or polluted, or in areas where chemical fumes are present, will generally require more frequent cleaning than those in residential areas. Lenses lose efficiency due to the action of wind-blown grit. At the time of cleaning, lenses in poor condition should be replaced. Some lenses, however can be restored to usable efficiency by chemical treatment. When glass reflectors are to be cleaned, the use of abrasive agents should be avoided to prevent loss of reflective efficiency from scratches. Special cleaners are required to clean polished aluminum reflectors properly.

3B-31 Location and Maintenance of Controllers

Controllers should be located where the likelihood of damage by motor vehicles is minimized. They should be located so that the service man can stand in a protected area and can have a clear view of the signal units being controlled.

Every controller shall be kept in effective operation in strict accordance with its predetermined timing schedule.

Timing.—**A careful check of the correctness of timed operation of the controller shall be made frequently enough to insure its operating in accordance with the planned timing schedule.** To check the timing, the length of each interval should be recorded for at least two complete cycles. These should then be checked against the timing schedule, a copy of which should be posted in the control-box cabinet. A complete check of traffic-actuated equipment should include the checking of the maximum timing by temporarily grounding the detector inputs in the controller. Where the controller is capable of operating in more than one dial, split, or offset, each should be independently checked. The checking of offsets can be facilitated by the preparation of a timetable for each controller in the system, and by the operation of the system on a predetermined cycle length during the time that the check is being made.

The checking of most timing functions can be done effectively in connection with periodic preventive maintenance or overhaul. The necessity for checking timing arises from the possibility of mechanical or electrical misadjustments or unauthorized changes of timing. The correction of faulty timing should be done only by capable, trained persons who have been duly authorized to perform controller repairs. Timing changes should be made only by authorized persons, using written instructions which describe details of each change.

Preventive maintenance.—**Controllers shall be carefully cleaned and serviced at least as frequently as specified by the manufacturer and more frequently if experience proves it necessary.**

Regularly scheduled preventive maintenance has been found to be more economical than waiting for serious controller trouble to occur. Some manufacturers recommend at least a yearly schedule.

Preventive maintenance servicing should include several steps. Controllers should be lubricated as shown in the manufacturer's instructions, but lubrication of other controller parts such as sealed bearings should be avoided. Electrical contacts, bearings, and wiring should be inspected and any worn or weak parts should be replaced. An accuracy check should be made of all timing motors, including synchronous, induction, and frequency responsive motors.

In the adjustment and overhauling of controllers, the tools recommended by the equipment suppliers should be used.

Availability of a spare unit for each type of controller minimizes the interruption to signal operation when a controller must be removed for routine servicing or emergency repair.

3B–32 Painting

Signal heads, brackets, poles, posts, control boxes, housings, and conduits above ground should be repainted at least every 2 years, and as much oftener as may be necessary to prevent corrosion and to maintain the good appearance of the equipment.

The frequency with which repainting is needed will vary with the paint, the condition of the surface to which it is applied, chemicals in the atmosphere, nearness to salt water, and other conditions.

The insides of visors or hoods and the entire surface of louvers or fins used in front of signal lenses shall be painted a dull black to minimize light reflection to the side of the signals. This is necessary for the same reasons as is adequate shielding of signal lenses (sec. 3B–9).

It is advisable to paint signals with colors which contrast with the visual background or with the light output of the signals. Highway yellow, dark green, and black have all been effectively used alone and in combination. Use of aluminum or silver paint which blend with the sky on bright days should be avoided.

3B–33 Maintenance Records

Detailed maintenance records should be kept and analyzed at regular intervals to determine future policies as to equipment purchases and the maintenance program.

Good maintenance records are valuable in a number of ways:

1. Careful analysis will assist in determining whether or not the maintenance program in use is satisfactory.
2. Analysis of costs will aid in deciding upon types of equipment to be purchased and improvements in maintenance methods.
3. Maintenance records will frequently be needed by the courts in connection with accident cases.

Maintenance records should indicate the necessary time required and costs of cleaning, lubrication, retiming, overhauling, lamp replacement, painting, and similar items for each signal installation, for each specific controller, and for each specific lamp failure.

C—COMPARISON OF PRETIMED AND TRAFFIC-ACTUATED CONTROL

Section 3C–1 Relative Adaptability to Normal Intersection Requirements

Each of the principal types of traffic signal control, pretimed and traffic-actuated, possesses certain advantages not afforded by the other. The choice of equipment should be made only after a review of the relative merits and adaptability to the particular requirements at the location proposed for signalization. The following discussion is intended to bring out basic differences in the different types of control, insofar as their operating characteristics and suitability for various traffic requirements are concerned. It should be remembered that each type of control is capable of being modified in various ways for improved efficiency and flexibility of traffic control.

With basic pretimed control, a consistent and regularly repeated sequence of signal indications is given to traffic. The total cycle length required for a complete sequence of indications may be adjusted from a minimum of 30 seconds to a maximum of about 120 seconds. In most basic pretimed controllers, changes in cycle length may be made in 5-second increments. By use of attached auxiliary devices or remotely located supervisory equipment to be discussed in sections to follow, the operation of pretimed control can be changed within certain limits to meet requirements of traffic more precisely.

Pretimed control is best suited to intersections where traffic patterns are relatively stable or where the variations in traffic that do occur can be accommodated by a pretimed schedule without causing unreasonable delays or congestion. Pretimed control is particularly adaptable to intersections where it is desired to coordinate operation of signals with existing or planned signal installations at nearby intersections on the same street or adjacent streets.

The traffic-actuated controller differs basically from the pretimed controller in that signal indications are not of fixed length, but are determined by and conformed within certain limits to the changing traffic flow as registered by various forms of vehicle and pedestrian detectors. The length of cycle and the sequence of intervals may or may not remain the same from cycle to cycle, depending on the type of controller and auxiliary equipment utilized to fit the needs of the intersection. In some cases certain intervals may be omitted when there is no actuation or demand from waiting vehicles or pedestrians.

Many operating variations are possible with traffic-actuated control. An intersection may be semi-traffic-actuated, which means that the green light is normally given to, and held by, the major street until a minor-street demand is registered. The green light is then given to the minor street for a period of time related to demand and then returned to the major street. This type of control finds frequent application at the intersection of an arterial street with a side street having relatively light and irregular vehicle and pedestrian traffic. By means of auxiliary devices, semi-traffic-actuated controllers can be coordinated with traffic signals at adjacent intersections, although this coordination is not usually as precise as with pretimed control.

Full traffic-actuated control provides for detector actuations on all approaches to the intersection. The controller is thus enabled to assign right-of-way substantially in accord with the demands of the several approaches. Some of these controllers are also capable of taking into account certain characteristics such as the spacing of approaching traffic and the waiting time of stopped vehicles.

For the signalization of arterial streets and of areas, a form of control termed "traffic-adjusted" is available which has some of the characteristics of both traffic-actuated and pretimed operation. Detectors are not used at each intersection, but the overall traffic demands are determined by sampling traffic volumes by automatic counting detectors at key locations. Computing equipment at a central control location constantly receives information from the sampling detectors, and adjusts the signal display within certain limits either continuously or at fixed intervals so as to provide optimum movement with respect to the currently dominant volumes and directions of vehicle movement.

3C–2 Advantages of Pretimed Control

Among the advantages of pretimed control are the following:

1. Consistent starting time and duration of intervals of pretimed control facilitates coordination with adjacent traffic signals, and provides more precise coordination than does traffic-actuated control, especially when coordination is needed with adjacent traffic signals on two or more intersecting streets, or in a grid system. This coordination may permit progressive movement and a degree of speed control through a system of several well-spaced traffic signals. Precise coordination may also permit maximum efficiency in the operation of two or more very closely spaced intersections operating under capacity conditions, when the timing relationship between intersections is critical.
2. Pretimed controllers are not dependent for proper operation on the movement of approaching vehicles past detectors. Thus the operation of the controller is not adversely affected by conditions preventing normal movement past a detector, such as a stopped vehicle or construction work within the area.
3. Pretimed control may be more acceptable than traffic-actuated control in areas where large and fairly consistent pedestrian volumes are present, and where confusion may occur as to the operation of pedestrian push buttons.
4. Generally the installed cost of pretimed equipment is less than that of traffic-actuated equipment and the former is simpler and more easily maintained.

A degree of simple coordination of pretimed controllers can be attained by use of controllers equipped with synchronous timing motors without wire interconnection or remote supervision. However, due to interruptions or irregularities of electric service which may occur, frequent patrol and adjustment of signals is required to assure reliable coordination in the absence of supervisory circuits.

3C–3 Advantages of Traffic-Actuated Control

At intersections where traffic volumes fluctuate widely and irregularly, where traffic loads shift frequently, or where interruptions to main-street flow must be minimized, maximum efficiency in signal operation may be attained by the used of traffic-actuated control.

Among the special advantages of traffic-actuated control are the following:

1. Traffic-actuated control may provide maximum efficiency at intersections where fluctuations in traffic cannot be anticipated and programed for with pretimed control.

2. Traffic-actuated control may provide maximum efficiency at complex intersections where one or more movements are sporadic or subject to variation in volume.

3. Traffic-actuated control will usually provide maximum efficiency at intersections of a major street and a minor street by interrupting the major-street flow only when required for minor-street vehicular or pedestrian traffic, and also by restricting such interruptions to the minimum time required.

4. Traffic-actuated control may provide maximum efficiency at intersections unfavorably located within progressive pretimed systems, where interruptions of major-street traffic are undesirable and must be held to a minimum in frequency and duration. A background time cycle may be superimposed upon the operation to effect coordination with nearby signals (sec. 3E–8).

5. Traffic-actuated control may provide the advantages of continuous stop-and-go operation without unnecessary delay to traffic on the major street, whereas isolated pretimed signals are sometimes switched to flashing operation during periods of light traffic.

6. Traffic-actuated control is particularly applicable at locations where traffic signal control is warranted for only brief periods during the day.

7. Traffic-actuated control tends to reduce any hazard associated with the arbitrary stopping of vehicles.

3C–4 Other Factors Governing Selection of Type of Control

The choice between pretimed and traffic-actuated control is frequently determined by initial equipment cost, installation cost, and anticipated operating expenses. Pretimed control is generally less expensive to install and maintain than other types of control. In considering the economic aspects in the selection of appropriate control apparatus, however, careful attention should be given to economic benefits or losses which may accrue to motorists and pedestrians. Unnecessary stoppages and delays to traffic movement result in economic losses which accumulate to a significant total during the life of the traffic control equipment. In many cases the reduction in motor-vehicle operating costs will justify installation of signal control equipment which has a higher first cost but greater efficiency in handling traffic.

Accident hazards also should be considered. While signals are most effective in reducing right-angle collisions, they tend to increase the frequency of rear-end collisions. Possible reduction of accidents through efficient operation of traffic signals frequently will offset added signal installation and maintenance costs.

Extreme care should be used in selecting traffic control equipment so that proper features for present and future operation will be obtained when controllers are purchased or can be added at a later date without excessive cost.

D—PRETIMED SIGNALS

Section 3D–1 Definition

A pretimed signal is a traffic control signal which directs traffic to stop and permits it to proceed in accordance with a single predetermined time schedule or a series of such schedules.

Operational features of pretimed signals, such as cycle length, split, sequence, offset, etc., can be changed according to a predetermined program.

3D–2 Advance Engineering Data Required

A comprehensive investigation of traffic conditions and physical characteristics of the intersection is required to determine the necessity for a signal installation and to furnish necessary data for the proper design and operation of a signal that is found to be warranted. Such data should desirably include:

1. The number of vehicles entering the intersection in each hour from each approach during 16 consecutive hours of a representative day. The 16 hours selected should contain the greatest percentage of the 24-hour traffic.

2. Vehicular volumes for each traffic movement from each approach, classified by vehicle type (heavy trucks, passenger cars and light trucks, and public-transit vehicles), during each 15-minute period of the two hours in the morning and of the two hours in the afternoon during which total traffic entering the intersection is greatest.

3. Pedestrian volume counts on each crosswalk during the same periods as the vehicular counts in paragraph 2 above and also during hours of highest pedestrian volume. Where young or elderly persons need special consideration, the pedestrians

may be classified by general observation and recorded by age groups as follows:

(a) Under 13 years.

(b) 13 to 60 years.

(c) Over 60 years.

4. The 85-percentile speed of all vehicles on the uncontrolled approaches to the intersection.

5. A condition diagram showing details of the physical layout, including such features as intersectional geometrics, channelization, grades, sight-distance restrictions, bus stops and routings, parking conditions, pavement markings, street lighting, driveways, location of nearby railroad crossings, distance to nearest signals, utility poles and fixtures, and adjacent land use.

6. A collision diagram showing accident experience by type, location, direction of movement, severity, time of day, date, and day of week for at least one year.

Additional data.—The following data are also desirable for a more precise understanding of the operation of the intersection and may be obtained during the periods specified in paragraph 2 above.

1. Vehicle-seconds delay determined separately for each approach.

2. The number and distribution of gaps in vehicular traffic on the major street when minor-street traffic finds it possible to use the intersection safely.

3D–3 Warrants for Pretimed Signals

Pretimed signals may be installed and operated only when one or more of the warrants defined in sections 3D–4 to 9 are satisfied, except that at intersections sufficiently far from other signalized intersections so that progressive timing is generally impractical, or at secondary intersections within a coordinated system, a traffic-actuated signal may be more appropriate than a pretimed signal. If traffic-actuated signals are installed at intersections within a coordinated system, such signals should be equipped and operated with control devices which provide proper coordination with adjacent signals. Sections 3E–2 and 3E–3 describe other warrants for traffic-actuated signals.

The investigation of the need for signal control should include an analysis of the degree to which each of the following warrants is met:

Warrant 1.—Minimum vehicular volume.

Warrant 2.—Interruption of continuous traffic.

Warrant 3.—Minimum pedestrian volume.

Warrant 4.—Progressive movement.
Warrant 5.—Accident experience.
Warrant 6.—Combinations of warrants.

When for a period of four or more consecutive hours any traffic volume drops to 50 percent or less of the stated volume warrants, it is desirable that flashing operation be substituted for conventional operation for the duration of such periods. However, such flashing operation should be restricted to no more than three separate periods during each day. (See sec. 3B–24 for additional discussion of flashing operation of traffic signals.)

3D–4 Warrant 1, Minimum Vehicular Volume

The minimum vehicular volume warrant is intended for application where the volume of intersecting traffic is the principal reason for consideration of signal installation. The warrant is satisfied when for each of any 8 hours of an average day the traffic volumes given in table 2 exist on the major street and on the higher-volume minor-street approach to the intersection.

Table 2.—Minimum vehicular volumes for warrant 1

Number of lanes for moving traffic on each approach		Vehicles per hour on major street (total of both approaches)	Vehicles per hour on higher-volume minor-street approach (one direction only)
Major street	Minor street		
1	1	500	150
2 or more	1	600	150
2 or more	2 or more	600	200
1	2 or more	500	200

The major-street and the minor-street volumes are for the same 8 hours. During those 8 hours the direction of higher volume on the minor street may be on one approach during some hours and on the opposite approach during other hours.

When the 85-percentile speed of major-street traffic exceeds 40 miles per hour, or when the intersection lies within the built-up area of an isolated community having a population less than 10,000, the minimum vehicular volume warrant is 70 percent of the requirements above, in recognition of differences in the nature and operational characteristics of traffic in urban and rural environments and smaller municipalities.

3D–5 Warrant 2, Interruption of Continuous Traffic

The interruption of continuous traffic warrant is intended for application where operating conditions on a major street are such that the minor-street traffic suffers undue delay or hazard in entering or crossing the major street. The warrant is satisfied when for each of any 8 hours of an average day the traffic volumes given in table 3 exist on the major street and on the higher-volume minor-street approach to the intersection, and the signal installation will not seriously disrupt progressive traffic flow.

Table 3.—Minimum vehicular volumes for warrant 2

Number of lanes for moving traffic on each approach		Vehicles per hour on major street (total of both approaches)	Vehicles per hour on higher-volume minor-street approach (one direction only)
Major street	Minor street		
1	1	750	75
2 or more	1	900	75
2 or more	2 or more	900	100
1	2 or more	750	100

The major-street and minor-street volumes are for the same 8 hours. During those 8 hours the direction of higher volume on the minor street may be on one approach during some hours and on the opposite approach during other hours.

When the 85-percentile speed of major-street traffic exceeds 40 miles per hour, or when the intersection lies within the built-up area of an isolated community having a population less than 10,000, the interruption of continuous traffic warrant is 70 percent of the requirements above, in recognition of differences in the nature and operational characteristics of traffic in urban and rural environments and smaller municipalities.

3D–6 Warrant 3, Minimum Pedestrian Volume

The minimum pedestrian volume warrant is satisfied when for each of any 8 hours of an average day the following traffic volumes exist:

1. On the major street 600 or more vehicles per hour enter the intersection (total of both approaches); or 1,000 or more vehicles per hour (total of both approaches) enter the intersection on the major street where there is a raised median island 4 feet or more in width; and

2. During the same 8 hours as in paragraph 1 there are 150 or more pedestrians per hour on the highest volume crosswalk crossing the major street.

When the 85-percentile speed of major-street traffic exceeds 40 miles per hour, or when the intersection lies within the built-up area of an isolated community having a population of less than 10,000, the minimum pedestrian volume warrant is 70 percent of the requirements above, in recognition of differences in the nature and operational characteristics of traffic in urban and rural environments and smaller municipalities.

A signal installed under this warrant at an isolated intersection should be of the semi-traffic-actuated type with push buttons for pedestrians crossing the main street. If such a signal is installed at an intersection within a coordinated system, it should be equipped and operated with control devices which provide proper coordination.

Signals installed under this warrant shall be equipped with pedestrian indications as provided in section 3F–2.

In connection with traffic control signals installed for school crossings, it should be understood that a traffic signal is not the only remedy nor is it necessarily the correct solution to the perplexing problem of traffic conflicts between vehicles and school children. Brief periods during which the hazards are unusually high are often better handled by officer control or adult crossing guards.

In some circumstances the pupils' response to traffic signal indications is so inadequate that the signal can become a contributory factor in increasing rather than decreasing accidents. The response to officer control or adult crossing guards is usually less uncertain.

It is therefore believed that traffic control signals should not ordinarily be installed at school crossings where schoolboy patrols or adult crossing guards can be used effectively, where students can be directed to cross at locations which are already controlled by traffic control signals or police officers, or where pedestrian refuge islands provide adequate protection.

Complete facts should be obtained and studied by competent traffic engineering authorities before decisions are made on the installation of signals in the vicinity of schools. As a result of these studies and consideration of the control methods listed above, traffic signals may be warranted if:

1. Pedestrian crossing volumes at a designated school crossing on the major street exceed 250 pedestrians in each of 2 hours; and

2. During each of the same 2 hours vehicular traffic through the designated school crossing exceeds 800 vehicles; and

3. There is no traffic signal within 1,000 feet of the crossing.

When the 85-percentile speed of major-street traffic exceeds 40 miles per hour or when the intersection lies within the built-up area of an isolated community having a population less than 10,000, the warrant is 70 percent of the requirements above, in recognition of differences in the nature and operational characteristics of traffic in urban and rural environments and smaller municipalities.

School crossing signals installed under this warrant should be of the pedestrian-actuated type. **They shall be equipped with pedestrian indications (sec. 3F–2).**

3D–7 Warrant 4, Progressive Movement

Progressive movement control sometimes necessitates traffic signal installations at intersections where they would not otherwise be warranted in order to maintain proper grouping of vehicles and effectively regulate group speed. The progressive movement warrant is satisfied when:

1. On an isolated one-way street or on a street which preponderantly has unidirectional traffic significance, adjacent signals are so far apart that the desired degree of platooning and speed control of vehicles would otherwise be lost.

2. On a two-way street, adjacent signals do not provide the desired degree of platooning and speed control; and the proposed and adjacent signals can constitute a progressive signal system.

Table 4.—System design speeds in relation to cycle length and signal spacing for single-alternate systems [1] [2]

Cycle length of system	Design speed for signal spacing of—		
	1,320 feet (1/4 mile)	1,000 feet (approx. 3/16 mile)	660 feet (1/8 mile)
Seconds	*M.p.h.*	*M.p.h.*	*M.p.h.*
40	45	34.1	22.5
45	40	*30.3*	20
50	36	*27.3*	18
55	32.7	*24.8*	16.4
60	*30*	22.7	15
65	*27.7*	21	13.8
70	*25.7*	19.5	12.9
75	24	18.2	12
80	22.5	17.1	11.3

[1] With identical speeds in both directions.

[2] Italicized numbers represent practical speeds.

In a single-alternate signal system (sec. 3D–19) the minimum spacings between the proposed signal and existing adjacent signals should closely approximate the distance D in feet, or full unit multiples thereof, given by the formula $D = CS \div 1.364$, where C = cycle length in seconds, and S = design speed of signal system in miles per hour. Table 4, illustrating the relationship between cycle length, signal spacing, and system speed, shows that signal spacings under 1,000 feet are not capable (with practical cycle lengths) of rendering progressive, two-way movement with acceptable speeds. It further indicates that desirable minimum signal spacing with 60-, 65-, or 70-second cycle lengths is approximately 1,320 feet or ¼ mile. The italicized speeds represent the practical speed ranges described above.

3D-8 Warrant 5, Accident Experience

The common opinion of the general public that signals materially reduce the number of accidents is rarely substantiated by experience. Not infrequently there are more accidents with signals in operation than before signal installation. Hence, if none of the warrants except the accident experience warrant described below is fulfilled, the initial presumption should be against signalization. Signals should not be installed on the basis of a single spectacular accident or on the basis of unreasonable demands and dire predictions of accidents which allegedly might occur. The accident-experience warrant is satisfied when:

1. Adequate trial of less restrictive remedies with satisfactory observance and enforcement has failed to reduce the accident frequency; and

2. Five or more reported accidents of types susceptible of correction by a traffic control signal have occurred within a 12-month period, each accident involving personal injury or property damage to an apparent extent of $100 or more; and

3. There exists a volume of vehicular and pedestrian traffic not less than 80 percent of the requirements specified in the minimum vehicular-volume warrant, the interruption of continuous traffic warrant, or the minimum pedestrian-volume warrant; and

4. The signal installation will not seriously disrupt progressive traffic flow.

Any signal installed solely on the accident experience warrant should be semi-traffic-actuated with control devices which provide proper coordination if installed at an intersection within a coordinated system, and normally should be full traffic-actuated if installed at an isolated intersection.

A traffic control signal, when obeyed by drivers and pedestrians, can be expected to eliminate or reduce materially the number and seriousness of the following types of accidents:

1. Those involving substantially right-angle collisions or conflicts, such as occur between vehicles on intersecting streets.

2. Those involving conflicts between straight-moving vehicles and crossing pedestrians.

3. Those between straight-moving and left-turning vehicles

approaching from opposite directions, if an independent time interval is allowed during the signal cycle for the left-turn movement.

4. Those involving excessive speed, in cases where signal coordination will restrict speed to a reasonable rate.

On the other hand, traffic control signals cannot be expected to reduce the following types of accidents:

1. Rear-end collisions, which often increase after signalization.

2. Collisions between vehicles proceeding in the same or opposite directions, one of which makes a turn across the path of the other, particularly if no independent signal interval is provided for these turn movements.

3. Accidents involving pedestrians and turning vehicles when both move during the same interval.

4. Other types of pedestrian accidents, if pedestrians or drivers do not obey the signals.

3D–9 Warrant 6, Combinations of Warrants

Signals may occasionally be justified where no one warrant is satisfied but two or more are satisfied to the extent of 80 percent or more of the stated values. These exceptional cases should be decided on the basis of a thorough analysis of facts.

Adequate trial of other remedial measures which cause less delay and inconvenience to traffic should precede installation of signals under this warrant.

3D–10 Selection of Type of Pretimed Control Mechanism

Where any of the previously described warrants is satisfied and the decision has been made to install a pretimed signal, it is necessary to select the type of pretimed control mechanism [14] to be used. The possible choices include the following, for which advantages are set forth in sections 3D–11 to 3D–13:

1. Nonsynchronous pretimed controller for isolated intersections.

2. Synchronous type of pretimed controller for isolated intersections.

3. Controllers providing for coordination.

3D–11 Nonsynchronous Pretimed Controllers for Isolated Intersections

This type of controller, which is timed by an electronic device, is not desirable and should be used only at unimportant isolated

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[14] *Pretimed, Fixed Cycle Traffic Signal Controllers*, Technical Report No. 2, Institute of Traffic Engineers.

intersections warranting signalization where it is unlikely that there will be any need for coordination with other intersections as long as the controller is to be used.

By use of auxiliary devices, cycle lengths and proportions allotted to the various go intervals can be changed a limited number of times during the day. However, traffic-actuated or synchronous pretimed equipment is preferable where such changes are desirable.

3D-12 Synchronous Pretimed Controller for Isolated Intersections

This type of controller uses a synchronous timing motor and should be used at isolated intersections where:

1. In the future, the installation is likely to be coordinated with other signal installations or to be supervised by a master controller.
2. A fixed length of cycle and intervals will be tolerable during all hours of traffic control operation.

In some applications a two-dial or even a three-dial controller may be used to provide two or three timing schedules, giving the controller flexibility to accommodate some changes in traffic patterns. Selection of schedule can be accomplished by use of program devices.

3D-13 Controllers Providing for Coordination

Several types of control are available for coordination. One of these involves the use of synchronous motors without supervision from a master controller. Other systems involve supervision of local controllers by the master controller through wire interconnection or by radio. Local controllers in these systems may employ synchronous or induction motors or electronic timing devices. Sections 3D-17 to 3D-21 discuss the various degrees of flexibility attainable by different systems. The selection should be based upon:

1. The total volumes of traffic involved.
2. The relative amounts of and variation in traffic on the several approaches to the intersection.
3. The variation in directional flow on each street.
4. An analysis of the differences in costs in relation to expected benefits to the motoring public.

In general, the noninterconnected (or nonsupervised) synchronous system should not be used for very heavy traffic because of its limitations as to flexibility and because of the absence of assurance that the desired coordination will continue indefinitely.

However, in some cases, sufficient flexibility may be obtained by programing multiple-dial controllers at a few problem locations. Visual power-failure indicators attached to local controllers are desirable accessories for maintenance of coordination.

3D-14 Signal Timing in Accordance With Traffic Requirements

The full value of a signal installation is realized only when it is operated in a manner consistent with the traffic requirements. The use of unduly long cycles, or improper division of cycles of reasonable length, fosters disrespect for and poor observance of signal indications. Signals should not be operated manually more than is absolutely necessary, as this type of operation has frequently proved to be more inefficient than properly timed automatic control. This is particularly true of signals in a coordinated system.

One of the chief difficulties in signal timing comes from the need to accommodate two or three radically different volume patterns at various times during the period of operation. Any timing plan which is devised should be checked against the traffic-count information collected to be sure that the inevitable volume changes on the streets concerned will be handled in the best possible manner.

Some of the factors which must be considered in assigning green time to the intersecting streets are:

1. Number of traffic lanes and other physical conditions.
2. Volume of traffic in the critical lanes.
3. Requirements of commercial and public-transit vehicles.
4. Vehicle headways on the intersecting streets.
5. Pedestrian requirements.
6. Vehicle and pedestrian clearance requirements.
7. Turning movements.

Signal timing can become exceedingly complex when it involves not one but a series of signalized intersections which are to be operated so as to provide for continuous movement of platoons of vehicles. Varying block lengths often constitute a major difficulty in arriving at a satisfactory timing plan. There are many details involved in the development of efficient time-space diagrams for progressive signal systems and no attempt is made to present a full treatment of the subject in this Manual. The Traffic Engineering Handbook, published by the Institute of Traffic Engineers[15], contains a helpful discussion of the significant details of signal timing and describes a number of practical re-

[15] *Traffic Engineering Handbook*, second edition, 1950. Institute of Traffic Engineers, 2029 K Street, N.W., Washington 6, D.C.

finements possible in traffic signal systems. The Highway Capacity Manual[16], published by the United States Bureau of Public Roads, also provides useful information on the influence of traffic elements at intersections.

3D-15 Division of Total Cycle Time

Reference has been made to the importance of assigning Go (green) time to the intersecting streets in accordance with the traffic demand. There follows a description of a method that has been employed successfully:

If, during the heaviest traffic hour, the effect of turning movements, slow-moving commercial vehicles, and other factors on the time spacing between vehicles in the critical lane leaving the intersection is equal for the two heavier traffic flows at right angles, the division of the total time cycle into the two Go periods will be approximately correct if these periods are made directly proportional to the intersecting volumes of traffic per critical lane.

However, if, during the heaviest traffic hour, there is a considerable difference in the time spacing between vehicles in the two intersecting critical lanes because of, say, the presence of trucks and buses in one of the critical lanes and not in the other, this fact should be taken into account. In making the cycle division, the Go periods will be approximately correct if made proportional to the products of the critical lane volumes and the time spacings on the respective intersecting streets.

As a simple illustration, assume that a 60-second cycle has been selected and that the time required for vehicles to clear the intersection after the green signal is 5 seconds on each street. This leaves a total of 50 seconds of Go time to be divided between the two streets. Assume that the critical lane volumes V_A and V_B on streets A and B during the heaviest traffic hour are 400 and 250 vehicles, respectively. In the first case, assume that the time spacing between vehicles, or headway on departure, for each of the two streets is the same. The Go time assigned to each street, T_A and T_B, would then be approximated as follows:

$$\frac{T_A}{T_B}=\frac{V_A}{V_B}=\frac{400}{250} \qquad (1)$$

and $T_A+T_B=50$ seconds (total Go time) (2)

Solving for T_B in (2) and substituting in (1):

$\frac{T_A}{50-T_A}=\frac{400}{250}$, whence $T_A=31$ seconds.

From (2), $T_B=50-31=19$ seconds.

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[16] *Highway Capacity Manual*, 1950. Bureau of Public Roads, Washington, D.C.

In the second case, assume that the time spacing between vehicles, or departure headway, H_A and H_B, is 3 seconds on street A and 5 seconds on street B. This difference in headway might be caused by a sizable percentage of trucks in the critical lane on street B. The division of the Go time would then be approximated as follows:

$$\frac{T_A}{T_B}=\frac{V_A \times H_A}{V_B \times H_B}=\frac{400\times 3}{250\times 5} \quad (3)$$

Solving for T_B in (2), and substituting in (3):

$$\frac{T_A}{50-T_A}=\frac{400\times 3}{250\times 5}, \text{ whence } T_A=24 \text{ seconds.}$$

From (2), $T_B=50-24=26$ seconds.

It should be emphasized that such elementary calculations provide only an approximate means of determining the proper time for each street. Other considerations, such as the time required for pedestrian crossings and physical conditions at the intersection, also affect signal timing. After the initial selection of a cycle length and a timing program, frequent checkbacks and studies of the signal in operation should be made to obtain the most efficient timing schedule.

As a general principle of traffic signal timing, no vehicle Go interval should be less than the time required for the waiting group of pedestrians to get started and to cross to a point of safety unless an exclusive pedestrian interval is also employed. Experiments with signal timing have shown that, insofar as vehicle movements are concerned, excellent efficiency can be attained under certain offpeak conditions with Go intervals as short as 15 seconds. Ordinarily, however, they must be somewhat longer to give the pedestrian a safe opportunity for crossing the roadway.

When the pedestrian crossing time runs concurrently with the vehicle Go period, which is the usual case, the total Go interval should be long enough to allow not less than 5 seconds during which it is indicated that pedestrians may start to cross, and enough longer to permit pedestrians who have entered the roadway to reach a place of safety with the additional time provided by the vehicular clearance interval. Thus if it takes 14 seconds for most pedestrians to cross the roadway or reach a point of safety, and if the vehicle clearance (yellow) interval is 3 seconds, the total Go (green) interval should be at least 5+14−3, or 16 seconds.

3D–16 Coordination of Pretimed Signals

In general, all pretimed signals within one quarter of a mile of one another and controlling the same traffic should be operated in coordination. Even at greater distances coordination may be desirable under certain conditions.

Great inconvenience and delay result from independent, non-interrelated operation of closely adjacent signal installations operating on pretimed control. Most of this delay can be eliminated by carefully planned coordination. However, under certain adverse conditions which seriously affect the efficiency of coordinated control, greater efficiency may be possible with traffic-actuated control, operated either independently or in combination with coordinated control (sec. 3E–8).

For required coordination with railroad grade-crossing signals, see section 3B–25.

3D–17 Types and Selection of Coordination

The most useful classification of traffic control signal systems is based on their method of coordination. Since the primary purpose of this coordination is to organize and facilitate traffic flow, it is essential to understand what vehicular traffic will do under the various systems. On this basis of classification there are four general types of coordination of pretimed signals. These are defined as the simultaneous system, the alternate system, the limited progressive system, and the flexible progressive system (secs. 3D–18 to 21).

3D–18 Simultaneous System

In a simultaneous system all signals show the same indication to the same highway at essentially the same time. This is one of the early types of signal systems and it has limited but important applications in modern traffic signal practice.

At all intersections the timing is essentially the same and indications change simultaneously or nearly so to show green at each signal facing the major-street traffic and red to all minor streets, and similarly throughout the cycle.

At normal traffic speeds the time required to travel between closely spaced intersections is so short that a very short cycle would be required for a flexible progressive or alternate system of control. If only two such intersections are to be coordinated, the best plan is generally to operate them as a simultaneous system, giving an ample green interval on the major street for a major portion of the traffic to clear through both intersections. If two such close intersections are encountered in a larger group to be coordinated, the best plan is to select the flexible progressive system and to adjust the offsets at the two closely adjacent intersections so as to interfere the least with the continuous movement of traffic. Frequently this will result in virtually simultaneous operation of these two signal installations.

Under conditions of heavy traffic, progressive signal systems may break down because of the accumulation of vehicles between signals. Under these conditions a simultaneous system may substantially improve operation of traffic in the system.

The simultaneous stopping of all traffic along the highway prevents continuous movement of vehicles and, particularly during low-volume periods, may result in high speed between stops but low overall speed. Also, cycle length and interval proportioning are usually controlled by the requirements of one or two major intersections in the system. This may result in serious inefficiencies at the remaining intersections.

3D–19 Alternate System

In the alternate system adjacent signals or groups of signals show opposite indications alternately along a given highway. In the single-alternate system opposite indications are shown by adjacent signals. Double- and triple-alternate systems consist of groups of two or three signals respectively showing opposite indications. The alternate system is usually an improvement over the simultaneous system in that throughout a series of intersections so controlled there can be, under favorable conditions, continuous movement of groups of vehicles at a predetermined speed, this being most efficient where the lengths of the blocks, or of the alternating groups of blocks, are equal and adequate. Alternate systems are exemplified by a one-half-cycle offset or advance start of green between adjacent signalized intersections.

An alternate system can be operated with a single controller, but this arrangement is not recommended, mainly because of the increased flexibility obtainable with local intersection controllers.

3D–20 Limited Progressive System

In the limited progressive system a fixed common time-cycle length is used and green indications are proportioned to conform with requirements of each intersection and are given independently in accordance with a timing schedule designed to permit continuous or nearly continuous movement of groups of vehicles along the highway at a planned rate of speed.

Supervision of a limited progressive system by a master controller through wire interconnection or by means of signals transmitted by radio may be used to maintain proper timing relations (offsets) between signals. Or synchronous-motor-driven controllers operated by a common or electrically synchronized source can be employed without interconnection or remote supervision by master control. However, power failures, severe dips in voltage, and variations in temperature may cause individual local controllers to fall out of step and disrupt planned movement of vehicles. In order to assure satisfactory operation periodic patrol of such systems is necessary. Visual power-failure indicators expedite detection of controllers not operating on the desired schedule.

3D–21 Flexible Progressive System

The flexible progressive system incorporates all features of a limited progressive system and has a number of additional features, depending on the type of intersection controller, master controller, and appurtenances selected. A common time cycle is used throughout the system. However, the length of the cycle can be changed as frequently as desired.

Through use of modern multiple-dial intersection controllers it is possible to establish several schedules for division of the cycle. In addition, it is possible to change offsets as frequently as desired. Predetermined timing programs can be set up on multidial controllers to favor rush-hour traffic movements at appropriate times during the day or week, offpeak traffic demands, and other traffic conditions. With this flexibility it is possible to meet efficiently the varying demands of traffic at each intersection and in the system.

Synchronous timing motors operated from a variable-frequency power source can give several different cycle lengths, and the number of possible timing schedules can be expanded accordingly.

Supervision of intersection controllers can be accomplished by direct wire interconnection from a master controller, by means of radio signals transmitted from a master control station, or by leased telephone lines. Wire interconnection can involve use of multiple conductor cables with one conductor assigned to each program function in addition to a common ground conductor.

An alternate type of wire interconnection involves use of two-conductor circuits carrying coded tone pulses from the master controller which are converted by a decoding device at the intersection controller into signals which select the desired timing schedule. Systems involving use of radio for coordinating traffic signals are similar to the two-conductor wire system except that tone pulses are transmitted and received by radio instead of by wire. Transmitting equipment and operators must be licensed by the Federal Communications Commission.

In any flexible progressive system knowledge of demands of traffic must be available in order to select appropriate timing schedules. Counts of traffic and measurements of vehicle speeds are essential to determine proper cycle lengths, cycle division, and offsets. In order to take full advantage of flexibility, measurements of traffic should be made frequently. In general, a properly designed and operated flexible progressive system is the pretimed system best adapted to efficient movement of traffic. Its advantages include the following:

1. With adequate highway capacity and favorable signal spacing, continuous movement of entire groups of vehicles is possible with a minimum of delay and at an average speed planned for the system.

2. A high degree of efficiency results from proportioning Go periods to fit traffic requirements at each intersection.

3. More uniform speeds are encouraged.

4. Differences in block lengths are better handled than with other pretimed systems.

3D–22 Conditions Affecting Efficiency of Signal Systems

Certain conditions seriously reduce the efficiency of signal systems, even of the best flexible progressive systems. Among these are:

1. Very short signal spacing (this particular condition does not affect the simultaneous system).

2. Inadequate highway capacity and interferences from parking and loading operations.

3. Traffic composed of units of widely differing speeds, such as streetcars, buses, trucks, and passenger automobiles, especially on narrow streets.

4. Certain types of complicated intersections, such as those requiring three or more phases per cycle.

5. Heavy volumes of vehicles turning from or into the artery, especially if the block into which they turn is short or otherwise limited in capacity.

6. Exclusive pedestrian intervals.

3D–23 Manual Control

At heavily traveled intersections operating under isolated control, manual operation of signals at certain times may be warranted by varying traffic requirements. The provision of apparatus to permit manual operation of signal installations in a flexible progressive system, however, is not generally recommended.

Experience has shown that if manual-control features are available a tendency on the part of the police to operate certain intersections manually is likely to develop. This often destroys coordination at those intersections and through the system, with disadvantages generally more important than the possible improvement achieved by proportioning intervals manually. The presumption should be strongly against manual control in coordinated systems until the inability of automatic control to meet the situation at the particular intersection is proved.

3D–24 Speeds for Progressive Systems

A speed or speeds for which a flexible progressive system is designed should accord reasonably with what speed studies show would be the speed of vehicle movement if cross-traffic delays were eliminated. After drivers have become accustomed to a progressive system it may be possible to increase the speed with safety.

High speeds should be avoided, especially in busy urban districts. Progressive systems along urban arteries are generally timed for speeds ranging from 20 to 30 miles per hour, although in outlying areas, under favorable circumstances, higher system speeds may be desirable. In general, the more heavily used the artery, the narrower the roadway, the more built-up and busy the district, the shorter the blocks controlled, the more mixed the types of traffic, or the more pedestrian and cross-street traffic there is, the lower should be the design speeds.

The relationship between signal-system design speeds and official regulations governing speeds must also be given careful attention.

3D–25 Signs Indicating Timed Speed

Traffic signal speed signs may be erected to guide drivers if the speed for which traffic signals are set is substantially lower than speed limits in effect on streets in the signal system.

When signs specified in section 1C–37 are used, they shall be posted as near as possible to traffic signals and at such intervals as are necessary to inform traffic properly.

E—TRAFFIC-ACTUATED SIGNALS

Section 3E–1 Definition

A traffic-actuated signal is a type of traffic control signal in which the operation is varied in accordance with the demands of traffic as registered by the actuation of vehicle or pedestrian detectors. Traffic-actuated signals can be classified in three general categories:

Semi-traffic-actuated signal.—A type of signal in which means are provided for traffic actuation on one or more but not all of the approaches to the intersection.

Full traffic-actuated signal.—A type of signal in which means are provided for traffic actuation on all approaches to the intersection.

Traffic-adjusted signal.—A type of signal in which characteristics of signal display at local controllers in an area or for an artery are continuously varied in accordance with the receipt of traffic flow information supplied to a computing master control by sampling detectors located at typical flow points in the area.

3E–2 Factors Governing Selection of Type of Control

In each of these categories there are several different types, and cases to which they are especially applicable (secs. 3E–5, 3E–6 and 3E–7, respectively). In addition, there are special applications such as pedestrian actuation, one-way restricted zone control (sec. 3B–26), and others.

The variety of types and applications of traffic-actuated control available makes it essential that a thorough knowledge of traffic and physical facts be obtained prior to selecting equipment for installation.

In some instances traffic-actuated equipment has been installed primarily for the purpose of speed control, either in conjunction with intersection control or for midblock locations. Traffic signals are not particularly effective in speed-control applications and the use of traffic-actuated equipment for this purpose is accordingly not recommended.

3E–3 Warrants for Intersection Control

When the installation of pretimed signals is warranted, consideration should also be given to the use of traffic-actuated signals. However, because traffic-actuated signals at intersections are responsive to rapid fluctuations in traffic conditions and do not normally delay traffic unnecessarily, it is not advisable to set values of minimum traffic volumes or other fixed warrants for their installation. There are a number of factors that should be considered and weighed before selecting and installing such signals:

Vehicular volumes.—At intersections where the volume of vehicular traffic is not great enough to warrant pretimed signals, traffic-actuated signals may be applied if other conditions indicate the need for traffic control signals and justify the cost of the installation.

Cross traffic.—When the volume of traffic on the major street is so great as to restrict and jeopardize unduly the occasional movement of vehicular or pedestrian cross traffic on the minor street, semi-traffic-actuated signals may be installed to provide for assignment of right-of-way to the minor movement. However, the movement of major-street traffic may be unduly and unnecessarily interrupted if traffic on the minor street is heavy enough to call for the right-of-way at frequent intervals. In such cases it may be necessary to limit the amount of green time for the minor street (sec. 3E–5).

Peak-hour volumes.—When traffic control signals are required at an intersection during only a small part of the day, such as during peak traffic hours, traffic-actuated signals may be installed if economically justified, since they will not unduly delay traffic at other times.

Pedestrian Traffic.—When only the minimum pedestrian volume warrants (sec. 3D–6) for pretimed signals are met, traffic-actuated signals should be considered. They will delay vehicular movements only when the streets are in use by pedestrians.

Accident hazard.—When only the minimum accident-experience warrant (sec. 3D–8) for pretimed signals is met, use of traffic-actuated signals should be given consideration, as they may lessen the stops and delays which are commonly associated with accidents after signalization. Traffic-actuated signals may be economically justified at locations where the accident experience is less than that warranting pretimed signals, but careful analysis should be made to assure effective results.

Wide traffic fluctuations between streets.—When the relative volumes of traffic on the entering streets fluctuate widely at an intersection where pretimed signals are warranted, full traffic-actuated control will usually provide the greater efficiency in intersection operation.

Complicated intersections.—When traffic signals are warranted at complicated intersections requiring multiple traffic phases, use of traffic-actuated signals should be given consideration because, in addition to the usual advantages of traffic actuation, a phase can be skipped when there is no traffic to use it.

Progressive signal systems.—When the spacing or character of an intersection in a pretimed progressive signal system is such that satisfactory progressive timing cannot be achieved, traffic-actuated control can be employed to advantage (sec. 3E–8).

3E–4 Warrants for Nonintersection Control

Special conditions at roadway locations other than intersections may warrant the installation of traffic-actuated signals. Some of the factors that may justify such installations are:

One-way restricted zones.—At locations on two-way roadways where traffic can move in only one direction at a time, such as at narrow bridges and tunnels, or on construction projects, traffic-actuated signals can be used effectively. (sec. 3B–26)

Nonintersectional pedestrian crossings.—Pedestrian crossings concentrated at schools or other major pedestrian crossings where intersections are a considerable distance apart may justify use of pedestrian-actuated signals (sec. 3D–6).

The installation of signals between intersections for the purposes indicated above should be accompanied by the erection of appropriate signs advising the motorists of this special application. Immediately subsequent to installation there should be a period of strict enforcement so that disrespect for signal indications will not develop.

3E–5 Semi-Traffic-Actuated Control

Semi-traffic-actuated control is applicable primarily to an intersection of a heavy-volume, high-speed traffic artery with a relatively lightly traveled minor road or street. Detectors are located only on the minor approaches. The signal is normally green on the major street, changing to the minor street only as a result of vehicle or pedestrian actuation thereon. In some types of controls the minor-street green interval is of fixed duration, which is undesirable. In the more flexible types the duration of the minor-street green interval is proportioned to the traffic demand thereon, with provision for a maximum limit beyond which the green light cannot be retained on the minor street even when traffic demand thereon is heavy. Upon the expiration of the required or maximum minor-street phase, the green indication reverts to the major street, where it must remain for at least a predetermined minimum interval. At the expiration of this minimum interval the control is again free to respond to minor-street actuation. The semi-traffic-actuated control mechanism receives no actuation from traffic on the major street, and therefore may frequently assign the right-of-way to the minor street at the most inopportune times for major-street traffic. Hence the effective use of semi-traffic-actuated control is limited to intersections with very lightly traveled minor streets and to intersections in coordinated systems where major-street progression can be assured by means of a background cycle (sec. 3E–8).

3E–6 Full Traffic-Actuated Control

Semi-traffic-actuated control does not detect and measure the demands of all traffic streams, and full traffic-actuated control therefore should be selected for intersections where failure to take all demands into account will materially impair the efficiency of traffic movement. In full traffic-actuated control, detectors are installed on all approaches to the intersection. Right-of-way is assigned to a street only as a result of one or more actuations on that street. When there is no traffic on any street, the green indication will ordinarily remain upon the street to which it was last assigned, but when one street carries substantially more traffic it may be more efficient to return the right-of-way to that street. In the event of continued actuation on one street, transfer of right-of-way will be made to waiting cross traffic upon the expiration of a predetermined maximum period, and then automatically return to the first street at the earliest opportunity. This opportunity cannot arise until a predetermined minimum green period on the cross street has expired.

The duration of the green indication for each street under normal traffic will fluctuate between the prescribed minimum and maximum values, depending upon the length of time between actuations on the street having the right-of-way. Under the more common type of full traffic-actuated control, the right-of-way will, upon actuations, be immediately transferred to the cross street if the length of time between actuations on the street having the green exceeds a predetermined value, and the minimum period for that street has expired. Hence the right-of-way is switched from street to street depending upon the frequency of gaps in traffic which exceed in length the predetermined time values for each street. With heavy traffic such gaps are relatively infrequent and the green periods are extended to their maximums. Under this condition traffic-actuated signal operation approaches that of pretimed signals.

The traffic-density type of full traffic-actuated control provides that the predetermined gap interval described above will diminish during each phase depending upon a number of traffic factors. Thus the probability that the green period will be terminated and the right-of-way transferred to the other street is increased by a thinning out of traffic moving on the green signal, by the passage of time during which traffic has been waiting on the red signal, and by the number of cars waiting on the red signal. These and other factors make the traffic-density full traffic-actuated control highly sensitive to traffic requirements under wide ranges of traffic volumes.

Full traffic-actuated control of either type can be applied to more than two-phase operations. Equipment is available for three- and four-phase intersections. Operation of controllers at such intersections is similar in principle to operation at two-phase intersections. Opportunity for the right-of-way is accorded to the several phases in rotation and phases for which there is no traffic demand are skipped. In three- or four-phase controls, provision can be made for allowing additional noninterfering traffic flows to move during more than one phase. Thus a three-phase control may handle four or five flows, provided only three of them are commonly interfering. Pedestrian actuation should be provided where necessary to assure a minimum green period of sufficient length for pedestrians or to establish pedestrian intervals (secs. 3E–9, 3F–7).

3E–7 Traffic-Adjusted Control

A combination of the advantages of a pretimed flexible progressive signal system and traffic-actuation can be realized by a system in which a traffic-actuated master controller is used to supervise either pretimed or semi-traffic-actuated local controllers. Detectors are placed at representative locations in the progressive system to provide the master controller with information concerning the traffic at those points. The master controller selects the cycle and offset combination predetermined to serve best the directional balance and volume characteristics existing at that time. The local controllers are connected to the master controller and operate at any given moment upon the cycle and offset selected by the master controller.

With traffic-adjusted control, transfer from one timing combination to another takes place quickly and with minimum interference to traffic moving during the changeover. If local controllers are semi-traffic-actuated, the duration of the minor-street phase within the selected cycle length is determined by actuations from detectors installed on the minor street. This system provides a wide degree of flexibility for effective coordination of traffic movements, either along a thoroughfare or in a network of streets.

3E–8 Other Coordinated Control

In addition to traffic-adjusted control there are other applications of traffic-actuated equipment in coordinated operation of a series of related signalized intersections, as follows:

Supervisory background cycle.—A supervisory background cycle can be imposed upon a series of semi-traffic-actuated controls by a master timer sending out impulses to each semi-actuated controller, or by local synchronous-motor control at each intersection.

The background cycle and offsets are determined in the same manner as for pretimed control to give the maximum travel band through the area. The function of the supervisory cycle is to assure that the local semi-traffic-actuated controllers provide at least the minimum main-street green interval in a time relation best suited to main-street progression. Each semi-traffic-actuated controller adds to its main-street green interval all time not required by traffic-actuated demand on the minor street, thereby providing the widest possible travel band. One possible disadvantage is that such an extended main-street green interval may seriously overload a subsequent intersection at which cross-traffic requirements are greater.

The type of operation just described obviously does not have the same speed-control characteristics as a pretimed progressive system, and hence should be used only where the consideration of moving maximum amounts of traffic with the least delay outweighs the considerations of speed control.

Special use in a pretimed progressive system.—A further application of traffic actuation in the field of coordinated movement occurs in a pretimed progressive system where intersection spacing at one or more points in the system is such that the best progressive timing arrangement involves considerable reduction or displacement in the travel band. Complicated intersections in a progressive system may also cause difficulties in the progressive timing. In these instances traffic-actuated control can sometimes be effectively employed to reduce the ill effects.

Mutual Coordination.—Mutual coordination is the coordination of two isolated semi-traffic-actuated controllers located at adjacent or nearby intersections in such a way as to minimize the stopping of traffic on the main artery. This is done by interconnecting the controllers so that there is a fixed offset between side street actuations.

3E–9 Pedestrian-Actuated Control

Operation of traffic-actuated signals must take into consideration the needs of pedestrian as well as vehicle traffic. This can be accomplished in the following ways:

1. **When pedestrian signals are not warranted in conjunction with a traffic-actuated signal installation (sec. 3F–2) but where occasional pedestrian movement exists and there is inadequate opportunity to cross without undue delay, pedestrian detectors shall be installed.** The pedestrian actuations may be handled on the same basis as vehicle actuations, provided that the minimum

green interval is adequate to serve pedestrians. In this case, no separate pedestrian signal indications are shown.

2. When pedestrian signals are not otherwise warranted but a pedestrian movement exists which would not have adequate crossing time with the above operation (sec. 3F–2 paragraph 7), pedestrian signals and detectors shall be installed and operated as prescribed in section 3F–7.

3. When pedestrian signals are warranted and installed in conjunction with a traffic-actuated signal, the operation should follow the patterns described in section 3F–7.

3E–10 Detectors and Controllers

The traffic-actuated signal, as its name implies, responds to vehicle or pedestrian actuations, and it is necessary that detector and controller equipment be designed for this service. In this respect traffic-actuated signals differ considerably from pretimed signals, which require no detector units and a somewhat simpler timing mechanism for their control. The general characteristics of the various types of detectors and controls that have been developed for use with traffic-actuated equipment are described below. More comprehensive descriptions and specifications are contained in standards adopted and published by the Institute of Traffic Engineers.[17]

3E–11 Types of Detectors

Four types of detectors are in common current use:

1. Pressure-sensitive detectors.
2. Magnetic detectors.
3. Radar detectors.
4. Pedestrian push-button detectors.

Other types have been used to a limited degree or are in stages of development, including:

5. Light-sensitive detectors.
6. Sound-sensitive detectors.
7. Infrared-ray-sensitive detectors.
8. Ultrasonic-sound-sensitive detectors.
9. Pneumatic detectors.

Each type has its advantages and disadvantages, and the selection should be made only after appraisal of physical and traffic conditions at the intersection.

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[17] *Traffic Actuated Traffic Controllers and Detectors*, Technical Report Number 3, Institute of Traffic Engineers, 1958.

3E–12 Pressure-Sensitive Detectors

A pressure-sensitive detector is installed in the roadway and is operated by the pressure of vehicle wheels passing over its surface. In general it may be thought of as an electric switch which is closed by the pressure of a vehicle wheel. It is capable of actuation by vehicles traveling at speeds up to 60 m.p.h. but is rendered inoperative if a car is stopped upon it. The detector is embedded in the pavement with the switch unit designed for removal and renewal as necessary. There are two types of such detectors:

Nondirectional detectors.—The detector is operated by traffic moving over its surface in either direction and has a single electrical contact.

Directional detectors.—The detector is operated by traffic moving over its surface in only one direction. Outwardly similar in appearance to the nondirectional detector, it has two sets of electrical contacts which are closed sequentially by vehicle passage and which operate into a special relay unit in the controller cabinet. This type of detector with its relay unit should be used whenever a detector may be subject to actuation by vehicles moving away from the intersection. It is less sensitive to high-speed vehicles than the nondirectional detector.

3E–13 Magnetic Detectors

Magnetic detectors are actuated by the disturbance of an electrical field caused by the passage of a vehicle, and are of two general types, noncompensated and compensated. Both types respond only to moving vehicles and are consequently not rendered inoperative or continuously operative by parked cars or other fixed metal objects within their zone of influence. Both types require auxiliary units to amplify the very small voltage generated in their coils by the passage of a vehicle.

Noncompensated detectors.—These detectors are usually installed in fiber conduit under the roadway surface and have an adjustable zone of influence up to 10 feet beyond either end of the detector. As the distance from the detector increases the sensitivity to slow-moving vehicles decreases, so that at maximum range only vehicles traveling at more than 12 m.p.h. are detected. Noncompensated detectors are not recommended for locations where a sharp cutoff is essential or where they are subject to external electromagnetic influences such as are caused by trolley buses and power lines.

Compensated detectors.—Detectors of this type involve two magnetic circuits and are so designed that their operation is not affected by extraneous electromagnetic influences. They are constructed for installation in the roadway pavement and are characterized by a relatively sharp definition of their zone of influence, usually extending only about 6 inches beyond each end of the detector. The best detectors of this type are capable of a high degree of directional discrimination and can, therefore, be used effectively on narrow streets.

3E–14 Radar Detectors

The radar detector is designed for mounting over the roadway and is actuated by the passage of a vehicle through its field of emitted microwave energy. It has limited directional characteristics, and is responsive only to vehicles moving at more than 2 m.p.h. It is not affected by parked vehicles or ordinary external electromagnetic influences. Its amplifying units and relays are self-contained. It has an adjustable zone of transverse influence of from 9 to 30 feet at normal mounting height.

3E–15 Pedestrian Push-Button Detectors

In addition to detectors for registering the demand of vehicles approaching an intersection, it is in many instances necessary that means be provided for registering pedestrian traffic demand. Pedestrian push buttons are used for this purpose and are properly regarded as a form of detector. In order to be suitable for traffic-actuation purposes, a push button must be designed to withstand rigorous service (sec. 3E–25).

3E–16 Adjustment Features of Traffic-Actuated Controllers

Traffic-actuated controllers must have a number of functional adjustments of sufficient range to provide the flexibility necessary to meet wide and sometimes rapid variations in traffic conditions at an intersection.

In semi-traffic-actuated control, the green interval is normally accorded to the major street, being called to the minor street upon actuation. The green interval for the minor street may be set for a given duration or may have the same initial portion and extensions described in the following paragraph for full traffic-actuated control. The major street does not have actuation, and its minimum green interval is determined by a minimum-period adjustment. At the end of this minimum period the green indication can again be transferred to the minor street in response to actuation. The major-street minimum period should therefore be set with due regard to expected major-street traffic conditions.

In full traffic-actuated control the green intervals for all approaches have an initial period to permit standing traffic to get into motion, followed by one or more unit extensions, as determined by the traffic demand. In the event of continued demand on an approach, with demand on the other street, the green phase is terminated by the operation of the extension limit. Vehicle-clearance intervals are provided at the end of every green interval. For each phase there is a recall switch, making it possible to require the green to return to that phase in the absence of actuations. With all recall switches on, the controller will in the absence of any actuations act as a pretimed control.

All of the features mentioned in this section should be readily adjustable by calibrated knobs, pins, or dials.

3E–17 Range of Adjustments for Semi- and Full Traffic-Actuated Control

The range of timing adjustments indicated in table 5 will cover normal operating conditions for semi-traffic-actuated and full traffic-actuated signal control. Timing adjustments should be on the basis of operating conditions at the intersection and should be periodically checked against actual performance.

Table 5.—Range of adjustments for semi- and full traffic-actuated control

	Range of timing adjustments	
	Semi-traffic-actuated	Full traffic-actuated
	Seconds	*Seconds*
Major-street minimum period	10–90	
Major-street initial period		2–30.
Minor-street initial period	2–12	2–30.
Major-street unit extension		2–30.
Minor-street unit extension	2–12	2–30.
Major-street extension limit		10–60.
Minor-street extension limit	10–60	10–60.
Vehicle clearance intervals[1]	Up to 10	Up to 10.
Pedestrian walk intervals[2]	5–35	3–35.
Pedestrian clearance intervals[2]	Up to 15	Up to 15.
Recall switches		ON-OFF.

[1] A range beyond the recommended maximum yellow clearance interval is provided to permit use of all-red clearance intervals (sec. 3B–23).

[2] If included.

3E–18 Range of Adjustments for Traffic-Density Control

The foregoing description of adjustments does not include those for traffic-density types of traffic-actuated controllers. Properly installed, adjusted, and maintained controllers of this latter type take account of a number of varying factors in their assignment of right-of-way. Included are the number of vehicles arriving against the red light, their waiting time, and the headway of vehicles moving on the green light. Adjustment of the minimum green time is automatically made with respect to the number of vehicles accumulated between the detector and the Stop line prior to the green interval. Some forms of controllers are capable of operation to facilitate platoon movement. All forms of traffic-density controllers are provided with specialized timing adjustments required for their operation. Adjustments for each phase of a typical two-movement controller of this class are indicated below:

		Range
Minimum green portions	seconds	5–60
Number of actuations before minimum green portion starts to increase	actuations	5–35
Added green portion for each actuation	seconds	1–20
Passage time from detector to Stop line	do	5–15
Allowed gap between actuations which is affected by waiting time of cars on other phase	do	10–1
Waiting time which affects above gap	do	10–90
Allowed gap between actuations which is affected by number of cars waiting on other phase	do	10–1
Number of waiting cars which affects above gap	cars	10–75
Allowed gap between actuations which is affected by headway of moving cars	seconds	10–1
Number of actuations per 10 seconds which affects above gap	actuations	10–75
Platoon carry-over effect	percent	10–90
Extension limit	seconds	10–90
Clearance interval [1]	do	up to 10
Recall switch		ON-OFF

[1] A range beyond the recommended maximum yellow clearance interval is provided to permit use of all-red clearance intervals (sec. 3B–23).

3E–19 Special Controller Equipment

The normal adjustment features of a traffic-actuated controller may not always be adequate to provide necessary or desirable features for special conditions. In some cases these features may be added internally and in others an auxiliary controller or timer is used. Some conditions of this character are as follows:

1. Necessity for pedestrian WALK and clearance intervals when pedestrian signals are included.

2. Necessity for an all-red clearance interval following the normal yellow vehicle clearance interval as might be required at unusually large or irregular intersections, or in one-way restricted zones.

3. Desirability of utilizing an alternate phasing with certain combinations of actuations. Such a situation occurs where nonconflicting left turns move during the same phase and all other traffic is stopped. When one of these turning movements is not present, however, it is possible to permit the movement of through traffic with which it would conflict. This can be accomplished with an auxiliary-movement controller, or special overlap relays.

4. Desirability of rendering certain detectors inoperative during some phases. In the above case, the through traffic is permitted to move during the left-turn phase only because of the absence of opposing left-turn traffic in that cycle. Unless the through-traffic detectors concerned are made inoperative during the left-turn phase, their actuations would falsely affect the relative time assigned to the through-traffic phase.

5. Provision for interconnection when a traffic-actuated signal is located within a pretimed progressive system (sec. 3E–8).

6. Provision for emergency features as might be required in conjunction with railroad crossings, emergency vehicles, civil defense, etc. (secs. 3B–25, 3B–27).

3E–20 Installation of Traffic-Actuated Signals

The installation of signal heads and controllers and of traffic-actuated signals involves the same considerations as those described in Sections 3B–1 to 33, which are applicable to all types of signals. However, since adjustments of the various control settings are frequently made in the field, it is particularly desirable to position the controller with a clear view of the approaches and with the controller cabinet door away from the intersection.

Details of the location and installation of vehicle detectors (secs. 3E–21 to 24) deserve special explanation because of their importance to the efficient and reliable operation of traffic-actuated signal equipment.

3E–21 Location of Vehicle Detectors for Semi- and Full-Traffic-Actuated Control

The placement of vehicle detectors in relation to the Stop line should be determined only after careful study and consideration of a number of factors, including type and operating characteristics of the controller, approach speed of vehicles, grade and width of the roadway, visibility, driveways, and channelized turning lanes. With conventional full and semi-traffic-actuated controller equipment under average conditions, table 6 will provide a basic guide subject to considerations discussed below.

The distances shown in table 6 are for a one- or two-lane approach at a level grade. With a wider roadway and with unrestricted visibility these distances may be increased if desired by 10 to 15 percent.

Where an intersection includes a channelized approach and separate turning lanes, certain detector spacings may have to be relatively short, due to limitations imposed by the length of the turning lane, the lower speeds of turning vehicles, and the need to avoid false actuations.

Table 6.—Placement of detectors in relation to other factors

85-percentile speed of approaching traffic	Distance from Stop line	Approximate minimum initial period [1]	Approximate minimum unit extension [1]
M.p.h.	*Feet*	*Seconds*	*Seconds*
Less than 20	110	11	4
20-30	140	15	4
30-40	170	18	4
Over 40	210 or more	23	4

[1] The sum of the initial period and one unit extension is the minimum green period displayed.

The last two columns in table 6 indicate the approximate minimum dial settings that should be used for the various detector-to-Stop-line distances. These minimum values will insure that vehicles actuating a detector get a green indication until the maximum limit for green time on that approach has been reached. A short spacing permits use of lower values for these settings, which result in quick responding control. A longer spacing, on the other hand, permits the controller to react to a vehicle farther away, and sometimes avoids an unnecessary stop by providing or extending the green period before the vehicle reaches the stop line.

3E–22 Locating Vehicle Detectors Near Commercial Driveways

If commercial driveways exist not too far from the normal detector locations, it is frequently possible to obtain satisfactory results by departing somewhat from the distances given above. However, if the driveway is relatively close to the Stop line, it is advisable to install a special detector which will be traversed by a vehicle leaving the driveway. This detector should be a "calling detector" which operates only during the red phase. This arrangement permits the controller to function normally on the "running" detector, yet still assures that driveway traffic can call the right-of-way if no other traffic is present. Due to the extremely light traffic using driveways of single-family residences, special detectors are usually not provided for them.

3E–23 Location of Vehicle Detectors for Traffic-Density Control

For traffic-density type controllers, it is essential that relatively long distances be used between detector and Stop line, since these controllers derive much of their efficiency from their ability to receive information on approaching traffic as early as possible. For normal roadway and traffic conditions, the distances shown in table 7 have been found satisfactory.

Where the greatest platoon-movement effect is desired, the detector spacings on that street should be increased about 20 percent.

3E–24 Location of Vehicle Detectors from Centerline

Pressure-sensitive and compensated magnetic detectors should be placed transversely in the roadway so that all vehicles approaching the intersection will cross them with one or more wheels.

The pressure-sensitive detector nearest the centerline of the road should be located with its end about 3 feet from the centerline. If it is impossible to do so and still avoid unwanted actuations by some cars moving away from the intersection, a directional detector should be used (pressure-sensitive, compensated magnetic, or ultrasonic). On multilane approaches or one-way streets it is ordinarily necessary that a detector be placed in each lane, with no more than a 4-foot gap between detectors. It should be noted that volume-density controllers can in some cases be operated effectively with detectors only in selected lanes on each approach.

Transverse placement of the compensated magnetic detector is approximately the same as for the pressure-sensitive detector, bearing in mind that the former has a cutoff point that extends about 6 inches out from each end.

Table 7.—Placement of detectors for traffic-density control

85-percentile speed of approaching traffic	Distance from Stop line
M.p.h.	*Feet*
20–30	240.
30–40	270.
40–50	320.
Over 50	375 or more.

The noncompensated magnetic detector, when adjusted for maximum coverage, does not have a sharp cutoff point. Unless very wide coverage is desired, the recommended location is 6 to 12 inches beneath the pavement, under the path normally traveled by the right wheels of the vehicle. This type of detector is not well adapted to a situation where detection must be restricted to one lane.

The radar detector may be mounted from the minimum height allowed by law for overhead clearances (frequently 14½ feet) to a maximum of about 17 feet. When sharp definition is required, the minimum possible height above grade should be used.

3E–25 Installation of Pedestrian Detectors

Pedestrian detectors of push-button or other types shall be designed to operate on a circuit not to exceed 18 volts. They may be mounted on signal standards, wood or steel poles, or individual posts. They should be conveniently located near each end of crosswalks used to cross the intersection. A mounting height of 3½ to 4 feet above the sidewalk has been found best adapted to general usage. Permanent-type signs (sec. 1B–36) should be mounted above or in unit with the detectors, explaining their purpose and use. Where two crosswalks, oriented in different directions, end at or near the same location, the positioning of pedestrian push buttons should clearly indicate which crosswalk is actuated by each push button.

Special-purpose push buttons to be operated only by authorized persons should include a housing capable of being locked to prevent access by the general public. Instruction signs are not necessary in this case.

3E–26 Operation and Characteristics of Traffic-Actuated Signals

With all types of traffic signals it is necessary that appropriate equipment be installed to meet traffic requirements at a given location. Assuming the availability of such equipment, it is still necessary to adjust and operate the equipment as nearly as possible in accordance with the needs of traffic.

Continuing adjustment in the operation of traffic-actuated equipment is essential to efficient traffic control because of the numerous timing intervals and adjustment features which are instantaneously sensitive to traffic actuation. Traffic-actuated equipment is usually adjusted or modified by relatively simple dial controls requiring no cessation of operation, special tools, or shop work. However, the interrelationship between these dial controls and timing intervals is delicate and complex and must be carefully maintained for efficient traffic control. Therefore, trained and experienced supervision of the operation and adjustment of traffic-actuated equipment should continue beyond the initial installation and adjustment period.

The number and range of the possible adjustments and a description of their meanings are to be found in sections 3E–17 to 19 and 3E–27 to 29.

3E–27 Continuous Operation

Since traffic-actuated signals which are properly adjusted operate effectively in periods of light traffic and tend to cause a minimum of unnecessary delays, they should normally be operated at all times as stop-and-go devices. However, they may be placed on flashing operation because of certain special circumstances such as:

1. During breakdowns, repairs, or maintenance.
2. In conjunction with nearby pretimed signals on flashing operation.
3. Upon preemption by a railroad-crossing protective signal.

3E–28 Time Intervals and Adjustments

Greatest efficiency is obtained from traffic-actuated equipment only with careful adjustment of the various features provided. This often requires some trial and experimentation after the installation has been made, and it is recommended that only a qualified person make these adjustments (sec. 3E–26).

Controllers other than traffic-density type

The following may be used as a general guide to the proper setting of traffic-actuated controllers of other than the traffic-density type.

Major-Street Minimum Period.—In semi-traffic-actuated equipment this setting determines the major-street green interval. It should be selected in relation to the minor-street extension limit in the same manner in which pretimed signal phases are proportioned. It is normally not less than 20 seconds.

Initial Period.—The initial period plus one unit extension is the minimum green period on actuated phases. It will be given to one or more vehicles waiting at the intersection at the start of the green. The minimum green period must be adequate to clear the maximum number of vehicles which can stand between the detector and the Stop line. The initial period is normally not less than 7 seconds.

Unit extension.—This is the green interval provided for each vehicle as it passes the detector and should be determined by the passage time from detector to Stop line for the slowest vehicle common on the street. This adjustment also determines the length of gap which, if exceeded, permits the right-of-way to be transferred to the other street. It is normally set at a value of 3 to 5 seconds.

Extension limit.—The extension limit terminates the green phase only when continuous traffic prevails and cross traffic waits. When traffic becomes very heavy on both streets, the signal operates in effect as a pretimed signal, and the extension limit determines the proportion of time to be allotted to each street and establishes a cycle length as well.

Clearance interval.—The clearance interval is set at a value that will permit traffic to come safely to a halt when a red signal is displayed. **The vehicle clearance interval shall be not less than 3 seconds.** Where conditions warrant a clearance interval exceeding 5 seconds, it should be broken into a yellow clearance interval of 3 to 5 seconds and an all-red interval (sec. 3B–23).

Pedestrian interval and pedestrian clearance interval.—These settings should conform to the recommendations of section 3F–7.

Recall switch.—This feature requires the right-of-way to revert to the street selected whenever the unit extension or extension limit is exceeded on the opposing phase. It may be used to assure a rotation of right-of-way when one or more detectors are inoperative.

Two-phase traffic-density controllers

The following adjustments are unique to two-phase controllers of the traffic-density type. Multiphase controllers of this type have some but not all of the adjustments listed.

Minimum green, added green, and number of actuations.—With traffic-density equipment the minimum-green portion is set at a low value which will constitute the shortest green phase possible under extremely light traffic. The interval is increased from this value by the amount set on the added-green adjustment for each car which arrives on the red phase in excess of a number set on the number of actuations before minimum green starts to increase adjustment. The three adjustments should be so set that sufficient green will be available to clear the maximum number of vehicles which can be stored between the detector and the Stop line.

Passage time.—This setting is analogous to the unit extension discussed above. It should be set at a value sufficient to allow a car to travel from detector to Stop line at the prevailing speed on the street. Actuations received during the passage time immediately preceding the termination of a green phase are treated by the controller as if received on the red phase.

Allowed gap and waiting time.—These settings together determine the low value to which the unit extension on the green phase will reduce and the amount of time after the first cross-street actuation before this value is reached.

Allowed gap and number of waiting cars.—These settings have the same effect as those above except that the unit extension is reduced by the number of waiting cars rather than time.

Allowed gap and actuations per 10 seconds.—These settings enable the controller to react to the increase in headway or "straggling" of vehicles moving on the green phase. These settings together determine the low limit to which the unit extension for a phase will reduce and the frequency of actuation on that phase which will cause this reduction to take place.

Platoon carry-over.—This feature adds to the count of number of cars waiting on the red phase the selected percentage of the actuations received during the preceding phase. This acts to reduce the unit extension on the opposing green phase more rapidly and thus favor the first street during heavy traffic periods.

Recall switch.—The recall on traffic-density equipment differs from that previously described in that the right-of-way will revert to the street selected only if a gap exceeding the passage time occurs on the opposing green phase.

3E–29 Sequence of Intervals and Phases

The sequence of intervals with traffic actuation is determined by the demands of vehicles and pedestrians. With simple two-phase operation the various color sequences are provided in fixed order as the controller responds to the actuation on the two streets. While the sequence of intervals is always the same, the duration of intervals is governed by traffic demands.

Traffic-actuated controllers can be provided with means so that actuation or absence of actuation will cause skipping, splitting, or initiating of intervals for special purposes, such as for pedestrians and left-turn movements. Such installations require thorough engineering in order to obtain effective operation through skillful layout and timing of sequences.

The length of pedestrian and vehicle clearance periods shall be adequate for all possible sequences of phases.

F—PEDESTRIAN SIGNALS

Section 3F–1 Definition

Pedestrian signals are traffic signals erected for the exclusive purpose of directing pedestrian traffic at signalized locations.

3F-2 Warrants

Pedestrian signals shall be installed in conjunction with vehicular traffic signals already meeting one or more of the minimum warrants previously set forth for pretimed or traffic-actuated signals (secs. 3D-3 to 9; 3E-3, 4), under any of the following conditions:

1. When a traffic signal is installed under the pedestrian volume warrant (sec. 3D-6).
2. When pedestrians and vehicles move during the same phase and properly adjusted pedestrian clearance intervals are needed to minimize vehicle-pedestrian conflicts.
3. When an exclusive phase is provided or made available for pedestrian movement in one or more directions, all vehicles being stopped.
4. When heavy vehicular turning movements require a semi-exclusive pedestrian phase for the protection and convenience of the pedestrian.
5. When pedestrian movement on one side of an intersection is permissible while through vehicular traffic is stopped to protect a vehicular turning movement on the other side of the intersection.
6. When an intersection is so large and complicated or a street so wide that vehicular signals would not adequately serve pedestrians.
7. When the minimum green intervals for vehicles at intersections with traffic-actuated controls is less than the minimum crossing time for pedestrians and equipment is provided which extends the vehicular green time upon pedestrian actuation.
8. When multiphase or split-phase timing would tend to confuse pedestrians guided only by vehicle signal indications.
9. When pedestrians cross only part of the street, to or from an island, during a particular phase.

3F-3 Type of Control

The control of pedestrian signal indications may be accomplished with the timing mechanism normally employed with traffic signals, in which case the pedestrian phase or indication is given at a predetermined point during each cycle; or the control may be such as to permit the use of a push button to introduce the pedestrian phase or indication in accordance with the needs of pedestrian traffic.

As a general rule, the installation of pedestrian signals at non-intersectional locations is to be avoided. However, when such signals are required (by conditions such as listed in sec. 3E-4), the pedestrian-actuated type of control, coordinated with adjacent signals, should be employed.

3F-4 General Design Requirements

Pedestrian signal indications should attract the attention of and be clearly readable or understandable to the pedestrian both day and night and at all distances from 10 feet to the full width of the area to be crossed.

All pedestrian signals shall be rectangular in shape and shall contain the lettered messages WALK and DONT WALK. The two basic types described below and shown in figure 3-4 are approved as standard for pedestrian signals:

Gas-Filled Tubing Type.—**The letters shall be at least 4½ inches in height and shall be in two lines. The WALK indication shall be green and the DONT WALK shall be red. The messages shall consist of (a) gas-filled formed tubing, or (b) cut-out letters illuminated by gas-filled tubing.**

Incandescent type.—**The letters shall be at least 3 inches high. The WALK and the DONT WALK indications shall be in separate signal sections. The WALK lens shall be white glass meeting the latest standards of the Institute of Traffic Engineers[18], with either (a) all except the letters obscured by an opaque material, or (b) an opaque band at least 5⅝ inches high across the center of the lens obscuring all except the letters and a band of white at the top and bottom. The DONT WALK lens shall be orange glass, meeting the latest standards of the Institute of Traffic Engineers above cited, with all except the letters obscured by an opaque material.**

Wherever a WALK indication is provided there shall also be provision for a DONT WALK signal indication. Particular care should be given to the design and construction of the gas-filled tubing type of signal so that in case of an electrical or mechanical failure of the word DONT, the word WALK will also remain dark.

All pedestrian signals within one intersection shall be of the same approved type.

Former editions of this manual have authorized the message WAIT as an alternate to DONT WALK. WAIT is believed, however, to be less readily understood by pedestrians and is too easily mistaken for WALK. It is therefore deleted as a permissible standard.

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[18] In preparation, to be available in 1961.

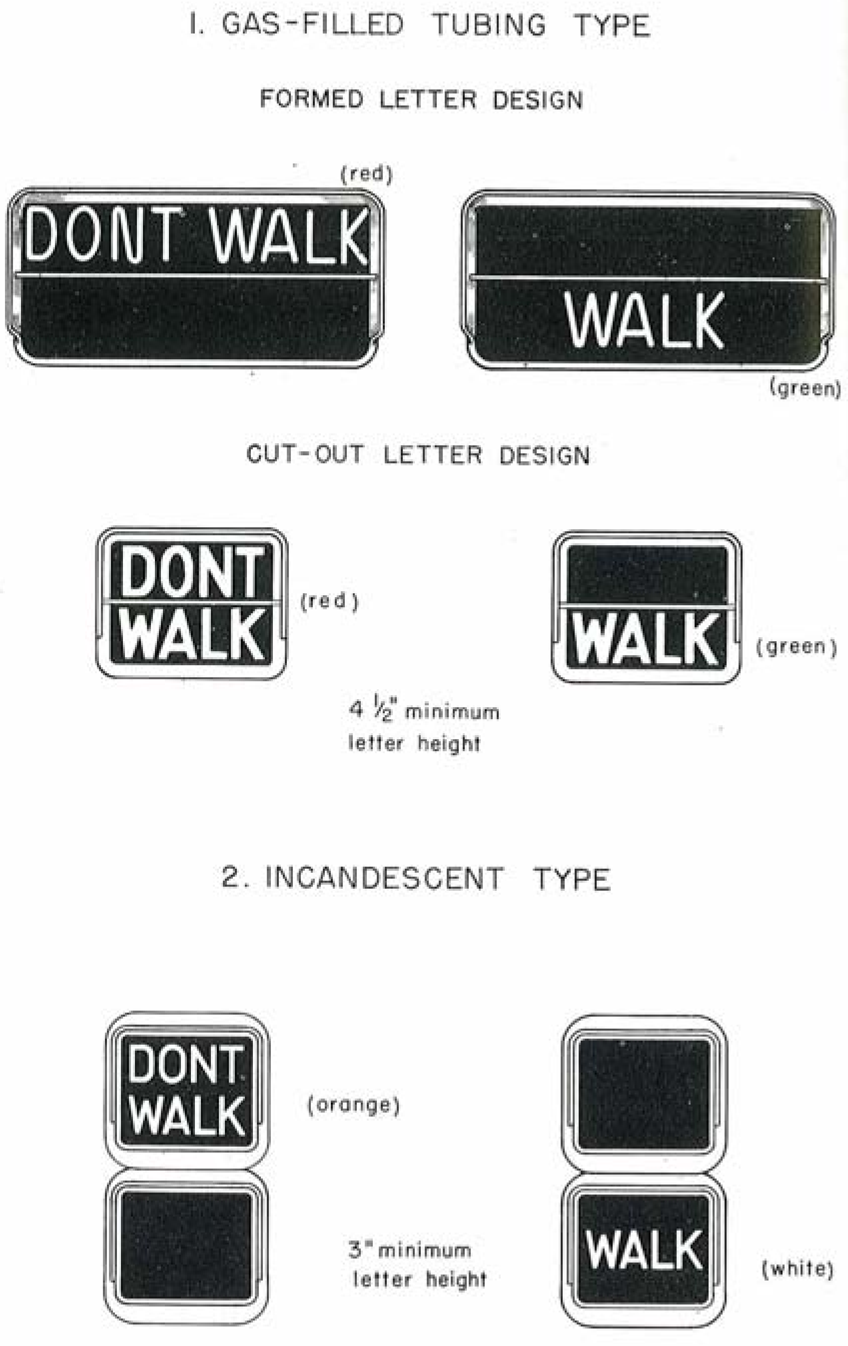

Figure 3–4. Pedestrian signal design standards.

3F–5 Meaning of Indications

The meanings of pedestrian signal indications are as follows:

WALK.—While the WALK indication is illuminated, pedestrians facing the signal may proceed across the roadway in the direction of the signal and shall be given the right of way by the drivers of all vehicles.

DONT WALK.—While the DONT WALK indication is illuminated, either steady or flashing, no pedestrian shall start to cross the roadway in the direction of the signal, but any pedestrian who has partly completed his crossing during the WALK indication shall proceed to a sidewalk, or to a safety island if one is provided.

3F–6 Location

Pedestrian signals shall be mounted with the bottom of the signal not less than 7 feet nor more than 10 feet above the sidewalk level and so that there is a signal in the line of vision of pedestrians crossing in any direction.

The DONT WALK indication shall be mounted directly above or integral with the WALK indication.

Pedestrian signals may be mounted separately or on the same support with vehicular signals. **When mounted with vehicular signals there shall be a physical separation between the two signal groupings.** Where feasible, the vehicular signal should not be directly visible from the start of the delineated crosswalk. **The pedestrian signal head shall be so positioned and adjusted as to provide maximum visibility at the start of the controlled crosswalk.**

Signals installed at nonintersectional crossings shall follow the usual location standards for both pedestrian and vehicular signals.

Pedestrian-actuated signals shall have a push-button detector 3½ to 4 feet above the surface of the sidewalk at each end of the crosswalks where actuation is required and on any island or median where a pedestrian may otherwise become stranded. A permanent-type sign explaining its use shall accompany each push-button detector (secs. 3E–25, 1B–36).

3F–7 Operation

Pedestrian indications shall be steady burning except during the pedestrian clearance interval, when the DONT WALK may be flashing. When traffic signals at the intersection are on standard flashing operation, pedestrian signals shall be extinguished.

There are several ways in which pedestrian signal intervals can be combined with vehicular signal intervals. Four basic combinations are described as follows:

Combined pedestrian-vehicular phase.—Signal phasing wherein pedestrians may proceed to use certain crosswalks parallel to the through vehicular movement and wherein vehicles are permitted to turn across the said crosswalks.

Semi-exclusive pedestrian-vehicular phase.—Signal phasing wherein pedestrians may proceed to use certain crosswalks with parallel or other vehicular movements, but wherein vehicles are not permitted to turn across these crosswalks during the pedestrian movement.

Leading pedestrian phase.—Signal phasing wherein an exclusive pedestrian phase, in advance of the minor-street vehicular phase, is provided for pedestrians crossing the main street only.

Exclusive pedestrian phase.—Signal phasing wherein pedestrians may proceed to cross the intersection in any direction during an exclusive phase while all vehicles are stopped.

In the operation of pretimed signals, when the minimum WALK interval plus the pedestrian clearance interval is greater than the interval necessary for vehicular traffic, the pedestrian interval shall govern and the vehicular interval shall be adjusted accordingly.

Vehicle-actuated signals may provide for pedestrian signal intervals timed as a normal part of the corresponding green interval for vehicles. **If the minimum vehicle interval is not of sufficient length to accommodate a pedestrian WALK and clearance interval, an additional interval for pedestrians shall be provided. This interval includes a WALK interval and pedestrian clearance interwal of adequate duration and shall be activated only by pedestrian actuation.** In the absence of a pedestrian actuation this interval is skipped and the DONT WALK indication remains.

Under normal conditions, the minimum WALK interval shall not be less than 7 seconds, so that pedestrians will have adequate opportunity to leave the curb, and in some cases complete the crossing, before the clearance interval is shown. However, the WALK interval itself need not equal or exceed the total crossing time calculated for the street width, as many pedestrians will complete their crossing during the clearance interval.

A pedestrian clearance interval shall always be provided. The duration shall be sufficient to allow a pedestrian crossing in the crosswalk to leave the curb and travel to the center of the farthest traveled lane before opposing vehicles receive a green indication. (Normal walking speed is assumed to be 4 feet per second.) On a street with a median at least 4 feet in width it is necessary to allow only enough pedestrian clearance time on a given phase to clear the crossing from the curb to the median. In the latter case, if the signal is pedestrian-actuated, an additional detector may be required on the island (sec. 3F–6).

G—SPECIAL TRAFFIC SIGNALS

Section 3G–1 Types of Special Traffic Signals

Special traffic signals include:

1. Flashing beacons.
2. Lane-direction-control signals.
3. Traffic signals at drawbridges.

Flashing Beacons

Section 3G–2 Definition and Application

A flashing beacon is a section of a standard traffic signal head or a similar-type device having a yellow or red lens in each face, which is illuminated by intermittent flashes.

Flashing beacons perform a useful function at locations where traffic or physical conditions do not justify conventional traffic signals. At other special points of hazard, experience has indicated that the flashing beacon is effective in calling the attention of drivers to these locations.

3G–3 Warrants

Flashing yellow beacon.—The installation of a flashing yellow beacon may be warranted as an advance warning device for an intersection or other location under one or more of the following conditions:

1. Physical obstruction existing in the roadway.
2. Important intersection hidden by an obstruction or sharp curve in the highway.
3. Hazardous horizontal and vertical alinement.
4. Special hazard or traffic regulation.

Flashing red and yellow beacon.—The installation of a flashing beacon at an intersection with yellow flashing on the main street and red flashing on the side street or streets may be warranted by one or more of the following conditions:

1. At intersections where sight distance is extremely limited or where other conditions make it especially desirable to emphasize the need for stopping on one street and for proceeding with caution on the other. This type of installation is effective at intersections where approach speeds are in excess of that warranted by conditions, and drivers need more notification than

can be provided by the use of standard or oversize Stop signs, by Stop signs and Advance Warning signs, or by Advisory Speed signs (secs. 1B–5, 1C–10, 1C–36).

2. A serious concentration of accidents susceptible of correction by the cautioning or stopping of traffic.

3G–4 Types of Control

A flasher device, usually installed in a separate housing remote from the beacon, is used solely to provide intermittent illumination of the beacon lens or lenses.

3G–5 Design

Flashing beacon units and their mountings shall follow the general design specifications for standard traffic signals, which include the following essentials:

1. Each signal unit lens shall have a visible diameter of not less than 8 inches.

2. The illuminating element, lens, reflector, and visor shall each be of such design as to render the lens when illuminated clearly visible to traffic facing the signal at all distances up to 1000 feet under all atmospheric conditions except dense fog.

3. The color of the lens shall be red for stop or yellow for caution, in accordance with Technical Report No. 1 of the Institute of Traffic Engineers.[19]

All flashing contacts should be equipped with filters for suppression of radio interference.

3G–6 Location

The particular purpose of a flashing beacon should largely govern its location with respect to the roadway and the hazard or other condition warranting the beacon. If used alone and located at the roadside, flashing beacons as measured from the bottom of the signal head should be at least 8 feet above the pavement. If suspended over the roadway, the clearance above the pavement should not be more than 17 feet or less than 15 feet. In no case should they be mounted on pedestals in the roadway unless the pedestal is within the confines of a traffic or pedestrian island.

3G–7 Operation

The illuminating element in a flashing yellow (caution) or flashing red (stop) beacon shall be flashed at a rate of not less

[19] *Adjustable Face Traffic Control Signal Head Standards*, Technical Report No. 1. Revised 1958, Institute of Traffic Engineers, 2029 K Street, N.W., Washington 6, D.C.

than 50 nor more than 60 times per minute. The illuminated period of each flash shall be not less than half and not more than two-thirds of the total cycle.

Flashing beacons generally should be operated continuously throughout the 24 hours of the day.

Lane-Direction-Control Signals

Section 3G–8 Definition and Application

Lane-direction-control signals are traffic signals used to indicate and control the direction of traffic movement on individual lanes of a street or highway. These installations are distinguished by signal units over each lane of the roadway; supplementary signs are often used to explain their meaning and intent. The most common use of lane-direction-control signals is for reversible lane control and details of this application follow (secs. 3G–9 to 14).

3G–9 Design

Lane-direction-control signals shall have one face for each direction of the traffic flow. Each face controlling a lane where the reversible system is in operation shall incorporate a distinctive rectangular signal unit (or units) of adequate size so that the signal indication is at all times clearly visible for 1,000 feet under all atmospheric conditions except dense fog.

The signals shall have a downward pointing green arrow and a red X symbol illuminated on an opaque background (fig. 3–5). Illumination of signals can be by incandescent lamps or gaseous tubing.

Mountings shall permit the signals to be suspended over lanes on cable or fixed supports.

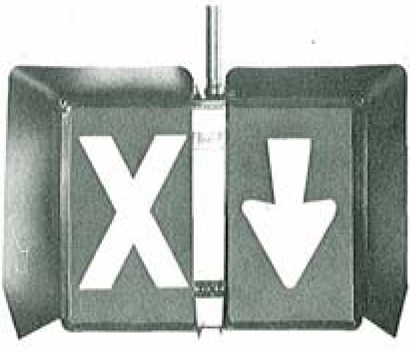

Figure 3–5. Typical lane-direction-control signal units.

3G-10 Meaning of Indications

The meanings of lane-direction-control signals are as follows:

Downward-pointing green arrow.—A driver facing this indication is permitted to drive in the lane over which the arrow signal is located. Otherwise he shall obey all other traffic controls present and follow normal safe driving practices.

Red X symbol.—A driver facing this indication shall not drive in the lane over which the signal is located, and this indication shall modify accordingly the meaning of all other traffic controls present. The driver shall obey all other traffic controls and follow normal safe driving practices.

3G-11 Warrants for Reversible-Lane Operation

The direction of flow of vehicular traffic lanes should be reversed only when competent engineering study shows not only that there is the need for reversible traffic flow, but also that the planned operation can reasonably be expected to operate safely and efficiently. Although warrants for reversible-lane control may be met, local conditions and experience may influence the decision as to their usage. Reversible-lane-control operation may be warranted:

1. When vehicular traffic flow in one direction on a two-way street, highway, bridge, or tunnel having three lanes or more shows the following characteristics:

(a) *Congestion.*—A street or highway can be said to be congested if the average speed of vehicles during peak periods decreases by at least 25 percent over normal period experience, or if there is a noticeable back-up at signalized intersections, so that most vehicles miss completely one or more green signal intervals. Under these conditions calculations will show a traffic demand in excess of rated capacity. Reversible traffic flow has been especially successful on routes where there is a high percentage of commuter traffic.

(b) *Periodicity of congestion.*—Since traffic lanes are usually reversed at a fixed time each day, the periods during which congestion occurs should be relatively stable and predictable.

(c) *Suitable ratio of directional traffic volumes.*—Reversing the direction of a lane requires that the additional capacity for the heavy direction be taken from the traffic moving in the opposite direction. Calculations of volumes per lane, based on a traffic count of all movements, will determine whether the number of lanes in the counter direction can be reduced, how many lanes shall be allocated to each direction, and the times at which the reversal should begin and end. Usually volume ratios of 66 to 75 percent in the predominant direction are taken as a basis for instituting reversible lanes.

(d) *Capacity at access and egress points.*—It is extremely important that there be adequate capacity at the terminal points of the reversible-lane system, with an easy transition of vehicles between the normal and reversed lane conditions. Installation of a reversible system with insufficient terminal capacity may result in an aggravation of the traffic problem and a waste of public funds.

2. When traffic movement at toll-booth areas requires reversal in direction of traffic flow for efficient operation.

3. When traffic movement in one direction at an entrance or exit of a parking lot at an industrial plant, stadium, shopping center, or similar facility greatly exceeds the capacity of the traffic lanes allocated for handling balanced traffic flow.

4. When a heavy traffic movement is slowed down and congested on a long uphill grade of a three-lane roadway because of slow-moving commercial vehicles traveling up the hill, thereby warranting the use, at times, of two lanes for uphill and one lane for downhill movement.

5. When temporary road conditions reduce the number of lanes normally available to handle traffic movement, even though it is extremely unbalanced at various periods of the day.

3G–12 Types of Control for Reversible-Lane Operation

The type of control provided for reversible-lane operation should be such as to permit either automatic or manual operation of the lane-direction-control signals. The control mechanism should permit the illumination of the red indications in both directions in the same lane for those lanes where the traffic flow is subject to being reversed. The possibility of an erroneous indication of green in both directions in the same lane should be avoided by wiring the green indication so that it can be illuminated only when the red indication shows in the opposite direction.

3G–13 Location of Signals for Reversible-Lane Operation

A lane-direction-control signal head with a face for each direction of reversible traffic to be controlled shall be located over the center of each reversible lane of the roadway at the beginning and end of the lane-controlled section. Confirming lane-direction-control signals over other lanes are optional. **If the area to be controlled is more than 1,000 feet in length, or if the vertical or horizontal alinement is curved, intermediate signal indications**

shall be placed over each reversible lane at frequent enough intervals so that motorists will at all times be able to see at least one indication and preferably two (due to the possibility of a burnout of a single indication) along the roadway, and will have a definite indication of the lanes specifically reserved for their use. At the terminal and intermediate signal installation points on the lane-controlled sections, signal indications above the reversible lanes shall be located in a transverse straight line at right angles with the roadway alinement. On roadways having intersections controlled by traffic signals, these lane-control indications shall be placed sufficiently far in advance of or beyond such traffic signals to prevent them from being misconstrued as traffic control signals. The use of twelve-inch traffic signal lenses may also aid in distinguishing the two types of signals (sec. 3B–6).

3G–14 Operation of Reversible-Lane Signals

All reversible-lane-control signals shall be coordinated and wired to a master control which will operate so as to permit signal indication faces for each direction in any of the reversing lanes to change from red to green or from green to red, except that the showing of green in both directions over the same lane shall be guarded against by electrical interlock. It also shall be possible to show a red indication in both directions in any of the lanes subject to reversing traffic flow. This latter feature permits the establishment of a neutral area or safety zone during the changeover period. The transitional interval, when both directions have a red indication, should be of sufficient length to minimize the hazard of opposite-direction conflicts on the reversible lane or lanes. The changeover should normally be made during a period of light traffic, but in an emergency traffic situation it can be made at any time.

The signals shall be operated continuously (sec. 3B–21).

Traffic Signals at Drawbridges

Section 3G–15 Application

Signals installed at drawbridges to control vehicular traffic are a special application of highway traffic signals.

3G–16 Warrants

Traffic signals shall always be used in conjunction with drawbridge gates. They should also be used with other types of protection commonly employed at drawbridges.

3G–17 Design

The traffic signal heads and mountings shall follow the standard design specifications of traffic signals. Drawbridge signals may be supplemented with bells which operate with the red signal indication to provide additional warning to drivers.

If prevailing approach speeds are in excess of 25 miles per hour, signal heads with 12-inch lenses and with 100-watt lamps or larger shall be provided (sec. 3B–6).

Where physical conditions prevent a driver from having a continuous view of at least one signal indication for approximately 10 seconds before reaching the Stop line, an auxiliary signal location shall be used to provide this visibility. If physical conditions make it impossible to provide any location which can be seen for 10 seconds in advance, a flashing yellow beacon (secs. 3G–2 to 7) or a Signal Ahead sign (sec. 1C–16) shall be erected in a suitable position to warn approaching traffic.

A flashing yellow beacon utilized in this manner may be interconnected with the drawbridge signal controller in such manner as to flash yellow during the period when drivers passing this unit at legal speed for the roadway section will encounter a red signal upon arrival at the signalized drawbridge approach.

3G–18 Location

Traffic signals shall be located at both ends of the movable span. To assure positive visibility two signal heads shall be mounted on each approach to the movable span. Their location should conform insofar as practicable with the standards for other signals (sec. 3B–12), except that one signal should be at the left side or over the left half of the roadway. They should ordinarily be not less than 50 feet nor more than 100 feet in advance of the movable span.

3G–19 Operation

Traffic signals at drawbridges shall be interconnected with the drawbridge gates, and, if feasible, with other signals on the same street or highway within 500 feet of the bridge. Not less than 15 seconds before the gates are closed, the signal shall change from green to yellow to red. While the gates are closed and the draw is open, the signals shall show a continuous red. After the draw is closed and the gates are opened, the indication shall change to a steady green and remain so until the next bridge opening.

If the drawbridge is close to a railroad grade crossing and there is a possibility that traffic may be stopped on the railroad crossing as a result of the bridge opening, a supplementary traffic signal may be required at an intersection on the approaches near the grade crossing. In this event extreme care should be used in planning the signal layout and operation so as to avoid the creation of confusion and hazard to motorists, either at the drawbridge or at the grade crossing. Normally such installations should be interconnected to provide coordination in signal indications under a given set of conditions. Other factors affecting railroad-highway grade crossings are presented in sec. 3B–25.

H—TRAIN-APPROACH SIGNALS AND GATES

Section 3H–1 Railroad-Highway Grade-Crossing Protection

At railroad-highway grade crossings where studies indicate the need of protection beyond that provided by signs, signals should be installed which indicate the approach and passage of trains. The signals may be supplemented by gates which extend across the lane or lanes of the approaching traffic while trains are approaching and occupying the crossing. The following sections apply only to signals and gates of the automatic type.

Where traffic signals are located at intersections in close proximity to the train-approach signals, particular attention must be given to the coordination of the two installations. (sec. 3B–25).

3H–2 Classification and Definitions

Railroad-highway grade-crossing signals are classified as flashing-light or wigwag signals, but both types should not be used at the same crossing.

A flashing-light signal is a signal in which indication of the approach of a train is given by two horizontal red lights flashing alternately at predetermined intervals.

A wigwag signal is a signal in which the indication of the approach of a train is given by a horizontally swinging disk and a red light enclosed in the disk.

A railroad-highway grade-crossing automatic gate is a device which, when indicating the approach and passage of a train, presents toward the highway in both directions the appearance of an arm being lowered to or in a horizontal position, and extending over the traveled roadway a sufficient distance to cover the lanes used by traffic approaching the crossing.

A No Right Turn or No Left Turn signal is a device which, when indicating the approach and passage of a train, presents the aspect of an illuminated sign bearing the legend NO RIGHT TURN or NO LEFT TURN, surmounted by a flashing yellow marker light.

3H-3 Warrants

Automatic signals or automatic signals and gates of the type described herein shall be installed at railroad-highway grade crossings where a study of the crossing by competent engineers indicates a need for advance warning of the approach of trains. This assembly of devices shall be used for no other purpose.

When a highway adjacent to and approximately paralleling a railroad intersects or joins another highway that crosses the railroad at grade, a No Right Turn or No Left Turn signal (secs. 3H-2, 6) may be used on the parallel highway to supplement the highway grade-crossing signals located at the crossing.

3H-4 Meaning of Indications

Railroad-highway grade-crossing signal indications shall have the meanings ascribed to them in the Uniform Vehicle Code, Section 11-701.

3H-5 Types of Control

Flashing-light and wigwag signals may be controlled either manually or automatically. **The flashing-light signal shall operate upon the approach of trains from either direction on the tracks for which protection is provided, and they shall continue to operate until the rear of the train reaches or clears the crossing. The control of No Right Turn and No Left Turn signals shall be correlated with the grade-crossing signal control.**

Automatic gates may be controlled either manually or automatically. **The gates shall operate upon the approach of trains from either direction on the tracks for which protection is provided. They shall reach the full horizontal position before the arrival of the fastest train operated over the crossing and shall remain down until the rear of the train has cleared the crossing.**

3H-6 Design

Flashing-light signals.—The following provisions relate to the design of flashing-light signals:

1. Signal lights shall be arranged to provide adequate indication to approaching vehicular traffic. They shall be mounted as shown in *Railroad-Highway Grade-Crossing Protection*, Bulletin No. 5 (or subsequent issue), Association of American Railroads, Train Operation, Control and Signals.[20]

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[20] Available from the Association of American Railroads, Transportation Building, Washington 6, D.C.

2. Electric-light units shall be in accordance with Association of American Railroads' Signal Section Specification 190 or 232.[21] Roundels and outer lenses shall be a minimum of 8⅜ inches in diameter and shall be in accordance with Signal Section Specification 69 of the Association of American Railroads.

3. The Railroad Crossbuck sign and the signal shall be mounted on the same post.

Wigwag signals.—The following provisions relate to the design of wigwag signals:

1. A wigwag signal shall consist of a disk 20 inches in diameter, in which a lamp with red lens or roundel is provided for night indication.

2. The disk shall be supported by a pivoted rod, and the length of stroke of the swinging light in the disk measured horizontally between extreme positions shall be 30 inches.

3. Lenses or roundels shall be in accordance with Signal Section Specification 69 of the Association of American Railroads.[22]

4. The railroad crossbuck sign and the signal shall be mounted on the same post.

Automatic gates.—The following provisions relate to the design of automatic gates:

1. An automatic gate used for the protection of highway traffic at a railroad-highway grade crossing, when indicating the approach of a train, shall present toward approaching highway traffic the aspect of an arm equipped with red lights being lowered across the lane or lanes used by traffic approaching the crossing, or at rest in the horizontal position across the lane or lanes.

2. An automatic gate, when installed, shall serve as an adjunct to a highway crossing signal of the flashing-light type. The gate should be mounted on the same assembly as the flashing-light signal; however, where conditions require, it may be mounted on an independent pipe, post, or pedestal located between the signal and the track.

3. The bottom of the gate arms, when in the horizontal or lowered position, shall be not less than 3½ feet nor more than 4½ feet above the crown of the roadway and, when not indicating the approach of a train, shall neither obstruct nor interfere with highway traffic.

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[21] Specifications available from the Communication and Signal Section, Association of American Railroads, 59 East Van Buren Street, Chicago 5, Illinois.

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[22] See footnote 21.

4. Each gate arm extending over the highway shall have three red lights shining in both directions along the highway. The light nearest the tip shall burn steadily and the other two lights shall flash alternately.

5. The gate arms shall be striped on both sides with 16-inch alternate diagonal stripes of white and black.

6. Lenses shall be in accordance with Signal Section Specification 69 of the Association of American Railroads.[23]

Insofar as practicable, the mechanisms should be so designed that if the arms, while being raised or lowered, strike or foul an object they will readily stop and, upon removal of the obstruction, assume the position required by the control mechanism.

No Right Turn and No Left Turn signals.—The following provisions relate to the design of No Right Turn and No Left Turn signals:

1. The aspect shall be that of an illuminated sign bearing the legend NO RIGHT TURN or NO LEFT TURN surmounted by a flashing yellow marker light.

2. The signal shall be in accordance with Association of American Railroads' Signal Section Specification 231.[24]

3. The marker light shall be in accordance with Signal Section Specification 190 or 232 of the Association of American Railroads,[25] except that it shall display yellow and be arranged for fastening to a bracket.

3H–7 Location

One signal or one signal and gate shall be placed on each side of the track or tracks, except in the cases of established one-way streets, where the installation shall be made on the approach side. Signals and gates shall preferably be placed on the right of approaching traffic.

The location of signals and automatic gates for railroad-highway grade-crossing protection should be determined after inspection and study at the site. In addition to providing for adequate clearances, consideration should be given to the type of highway, angle of crossing, and visibility to drivers approaching the crossing. The location of the signal should be not less than 2 feet beyond the curb, the edge of the traveled way, or the outer edge of the paved shoulder when the shoulder is continued across the tracks.

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[23] [24] [25] See footnote 21.

The No Right Turn or No Left Turn signal, when used, shall be placed as close to the intersection as practicable.

3H–8 Installation

Signals and gates shall be installed in accordance with the standards and practices recommended in *Railroad-Highway Grade-crossing Protection*, Bulletin No. 5 (or subsequent issue), Association of American Railroads, Train Operation, Control and Signals.[26] Figure 3–6 illustrates typical train-approach signal installations.

Figure 3–6. Train-approach signal installations at railroad-highway grade crossings.

3H–9 Operation

Signals and devices which indicate the approach of a train shall be so controlled that they will operate for such period of time

[26] Available from the Association of American Railroads, Transportation Building, Washington 6, D.C.

before the arrival of any train operated over the crossing as is reasonably required to afford protection. Where the greatest distance along the highway is 35 feet or less between the signal on either side of the crossing and the clearance beyond the farthest track from such signal on which trains operate at medium or higher speed, the signals shall operate for not less than 20 seconds before the arrival of any train on any such track. Where this distance is more than 35 feet, the 20 seconds should be increased to provide the additional time required for highway vehicles to clear the crossing.

Circuits for the operation of automatic gates shall be so arranged that the gate arm shall start its downward motion not less than 3 seconds after the signal lights start to operate. The gate arm shall reach full horizontal position before arrival of the fastest train operated over the crossing and shall remain in that position until the rear of the train has cleared the crossing.

Local conditions may require an operating time longer than 20 seconds before arrival of the train, but too long an operation by slow trains is undesirable. Uniform time control for all train speeds is the most desirable arrangement, and at crossings where there is considerable difference between high and low train speeds and where travel on the highway is heavy, provision for a type of circuit control that will insure equal or approximately equal timing should be considered.

Electric lamps in the flashing-light type of signals shall flash alternately. The number of flashes of each lamp per minute shall be 30 (minimum) to 45 (maximum). Each lamp shall be illuminated for approximately one half of the operating cycle.

Each flashing-light unit shall have a range in accordance with Signal Section Specification 190 or 232 of the Association of American Railroads. [27]

With the wigwag type of signal, movement of the swinging disk from one extreme to the other and back constitutes a cycle. The number of cycles per minute shall be 30 (minimum) to 45 (maximum).

The electric-light unit of the wigwag signal, when the disk is suspended vertically, shall have a range at night of 1,500 feet through a total angle of not less than 20 degrees when a 10-watt lamp rated at 1,000 hours is burned at rated voltage. The lamp shall burn while the disk is swinging.

The No Right Turn or No Left Turn signal shall be legible only when the crossing signal indicates the approach of a train.

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[27] See footnote 21.

It shall be illuminated without flashing during the period that the crossing signals are operating, and the yellow marker light shall flash in synchronism with the crossing signals.

3H–10 Maintenance

Automatic signals and gates shall be kept well painted and in a good state of efficiency. The surfaces of lenses on signal and gate-arm lights shall be kept free from such deposits as soot or other materials that will seriously affect their efficiency.