Part III

SIGNALS

A—INTRODUCTION

Section 158.—Definitions

Highway traffic signals include all power-operated traffic control devices, except signs, 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.

Section 159.—Value of Signals

The traffic signal is a valuable device for the control and safe facilitation of vehicle and pedestrian traffic. Because of its arbitrary 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 either to the advantage or disadvantage of the vehicles and persons controlled. Consequently, it is of 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 operated, usually have one or more of the following advantages:

1. They provide for orderly movement of traffic.
2. They reduce the frequency of certain types of accidents.
3. 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 control speed on through highways and main routes.
5. They can be used to interrupt heavy traffic at intervals to permit other traffic, pedestrian or vehicular, to cross.
6. They represent a considerable economy, as compared with manual control, at intersections where some definite means of assigning right-of-way first to one movement and then to another is required by the volumes of vehicular and pedestrian traffic, or by accident conditions.

There is a belief among 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. This stereotype plan of installation should be avoided.

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

A careful analysis of 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 a traffic signal installation may be justified. These warrants are presented in this manual for the several signal classifications.

Separate values are given for warrants for rural and urban areas, in recognition of differences in the nature and environment of traffic in these two general area classes. Drivers in rural areas are conditioned to relatively light traffic, and 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. An urban area is here considered to be a metropolitan region having a population of 5,000 or more. All other places, for the purpose of these warrants, are regarded as rural areas.

Section 160.—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 all lend themselves to a certain degree of standardization, and standards for such features are presented herein.

The increasing use of and need for train-approach signals and automatic gates at railroad grade crossings heighten the importance of standardization of this type of equipment. The principal features of design and operation that have been standardized by the Association of American Railroads are set forth in the portions of the text dealing with train-approach signals.

Section 161.—Legal Authority

Traffic signal indications would be unenforceable if placed by other than public authority. Unofficial traffic signals should be legally prohibited in all jurisdictions. The erection of signs or other devices that hide from view to interfere with the effectiveness of any traffic signal should likewise be prohibited. It is imperative that traffic signal indications be strictly observed and enforced. Suitable legislative models covering these points are presented in Act V of the Uniform Vehicle Code (art. III) and in the Model Traffic Ordinance (art. IV). The Code and the Ordinance authorize 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.

Section 162.—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 classified as follows:

1. Traffic control signals (Stop-and-Go):
   (a) Fixed-time signals (secs. 205-222).
   (b) Traffic-actuated signals (secs. 233-268):
       (1) Full traffic-actuated signals.
       (2) Semi-traffic-actuated signals.
       (3) Speed control signals.
2. Special pedestrian signals (secs. 269-276).
3. Other special traffic signals:
   (a) Flashing beacons and signals (secs. 278-283).
   (b) Lane-direction traffic signals (secs. 284-289).
   (c) Traffic signals at drawbridges (secs. 290-294).
4. Train-approach signals and gates (secs. 295-311):
   (a) Flashing light and wigwag signals.
   (b) Automatic crossing gates.

B—FEATURES COMMON TO FIXED-TIME AND TRAFFIC-ACTUATED SIGNALS

Section 163.—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 fixed-time and traffic-actuated signals, the difference between the two types being in the mechanisms that operate them. Standardization in those design factors that affect the traffic to be controlled is especially important. The sections of this subdivision contain all standards and requirements of this nature that are equally applicable to the two types of signals named. Standards applicable to but one type, including design features and methods of operation, are presented in subsequent subdivisions.

Section 164.—Design for Future Needs

Traffic control equipment should always be purchased with the future in mind. Flexibility which may not immediately be considered necessary will often be found desirable 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.

Section 165.—Number of Lenses per Signal Face

Each signal face shall have at least three lenses—red, yellow, and green. It may have additional lenses as indicated herein.

Experience has shown that the yellow indication serves several important traffic control functions that cannot satisfactorily be served by a two-lens signal face. These are:
1. The yellow signal acts as a cushion at the end of the Go interval and warns approaching traffic of a change in signal indication.
2. Cars within an intersection or other signalized area, as well as those ap-
proaching so closely that to stop would be hazardous, are given an opportunity
to clear.
3. Flashing yellow is important as a caution signal when the signal is not
being operated as a Stop-and-Go device.

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.
3. Right-turn arrow.

Lenses for the control of pedestrians may also be added to each signal
face, as specified in sections 272 to 274.

Section 166.—Color and Position of Lenses
All lenses shall be arranged in a straight and preferably vertical line and shall be in the following order, from top to bottom or
from left to right:

Position: 	 Signal indication
1. 	 Red
2. 	 Yellow
3. 	 Green
4. 	 Straight-through arrow
5. 	 Left-turn arrow
6. 	 Right-turn arrow
7. 	 Wait (or Don't Walk)
8. 	 Walk

All arrows shall be green on an opaque background. Walk-
Wait lenses which are incorporated in standard signal faces shall be of the design described in section 272.

The colors red, yellow, and green shall conform to the adjustable-face traffic control signal head standards of the Institute of Traffic Engineers, approved as an American Standard by the
American Standards Association (D-101-1942).

In addition to the foregoing lenses, special pedestrian signals
mounted apart from the traffic signal head may be provided as specified in sections 272 and 274.

Section 167.—Meaning of Color and Arrow Indications
Color and arrow indications in traffic control signals should have the meanings ascribed to them in this section 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 accord with Act V of the Uniform Vehicle Code (secs. 34, 36). The simultaneous illumination or overlapping of different color indications, except where green arrows are shown together with the circular red indication, or where pedestrian lenses are involved, is not recommended.

This section applies primarily to traffic control signals at inter-
sections, but appropriate interpretation can be readily made for use
of signals elsewhere, such as at school crossings, fire stations, and
drawbridges.

The meanings of the indications, which should be thus prescribed by
law, are as follows:

Green (alone):
1. Vehicular traffic facing the signal, except when prohibited by a superior
regulation, may proceed straight through or turn right or left unless a sign at
such place prohibits either such turn. But vehicular traffic, including vehicles
turning right or left, shall yield the right-of-way to other vehicles and to pedes-
trians lawfully within the intersection or an adjacent cross walk at the time
such signal is exhibited.
2. Pedestrians facing the signal may proceed across the roadway within any
marked or unmarked cross walk unless directed otherwise by a pedestrian signal.

Yellow (alone, following green):
1. Vehicular traffic facing the signal is thereby warned that the red or Stop
signal will be exhibited immediately thereafter, and such vehicular traffic shall
not enter or be crossing the intersection when the red or Stop signal is exhibited.
2. Pedestrians facing such signal are thereby advised that there is insufficient
time to cross the roadway, and any pedestrian then starting to cross shall yield
the right-of-way to all vehicles.

The yellow lens is required in standard signal apparatus for the
reasons indicated in section 165. Confusion has frequently arisen from
the misuse of this lens. When the length of 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.

Red (alone):
1. Vehicular traffic facing the signal shall stop before entering the cross walk
on the near side of the intersection or, if none, then before entering the inter-
section, and shall remain standing until a green signal 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.

Confusion and serious hazard result from lack of uniform obedience
to red signals. The red indication should always mean that each ve-
hicle shall stop and shall not proceed farther until a Go signal ap-
ppears, unless specifically authorized by one of the auxiliary indications
described below.

Red with green arrow:
1. Vehicular traffic facing such signal may cautiously enter the intersection
only to make the movement indicated by such arrow, but shall yield the right-
of-way to pedestrians lawfully within a cross walk and to other traffic lawfully
using the intersection.
2. No pedestrian facing such signal shall enter the roadway unless he can
safely and without interfering with any vehicular traffic, or unless a separate
Walk Indication is shown.

Permitting vehicle operators to make right or left turns during the
showing of the red signal without a modifying arrow is bad practice.
It weakens the single meaning of the red indication. The practice
cannot be permitted at all intersections, and, therefore, cannot be
followed uniformly. It adds to pedestrian hazards and inconvenience,
and creates hazards and delays for vehicle movement.

The appropriateness of right and left turns proceeding during the
Stop period is exceptional and therefore these movements, when nec-
cessary, deserve a specific modifying indication, as is provided by the
right- or left-turning arrow lens. If such turning arrows are shown

1 Adjustable Face Traffic Control Signal Head Standards, Technical Report No. 1, Insti-
tute of Traffic Engineers.
and should be replaced with properly designed lenses as promptly as possible. Figure 21 shows the details of an arrow lens design developed by the Committee on Standards of the Institute of Traffic Engineers from numerous field tests under both day and night conditions.

Section 169.—Lettering on Lenses

Lettering shall not be used on lenses. This does not apply to special pedestrian signs (sec. 272).

The practice of embossing GO on green lenses, CAUTION on yellow lenses and STOP on red lenses reduces the effectiveness of the lenses. With the spread of uniform meanings and positions, the need for such lettering is constantly decreasing.

Section 170.—Illumination of Lenses

Each lens shall be illuminated independently of any other lens. The illumination shall be by a clear lamp of not less than 40-watt capacity, especially designed for traffic signals.

This provision is not intended to preclude the use of other properly designed light sources, such as those utilizing gaseous mixtures, which produce an equally effective signal lens indication.

Independent illumination of each lens is essential to permit uniform position of lenses, give satisfactory brilliance, and provide the necessary flexibility in signal indications. Special lamps with sturdy filaments and other appropriate characteristics have been designed to meet traffic signal requirements. A 60-watt lamp has been most generally used, but 67-watt and 40-watt traffic signal lamps are also available.

The 40-watt lamps are economical in current consumption but should be used only when the lens transmission factor is sufficient to give a conspicuous indication and when there are no confusing background lights or sun glare.

For most effective indications, traffic control signal lamps should be operated at full voltage, rather than under voltage. When lamps
rated at a higher voltage than the actual voltage at the lamp socket are used, longer lamp life results, but at the expense of light output and signal brightness.

More desirable than the above practice is the use of higher wattage lamps which will give the equivalent light output with a longer life. To serve this purpose the 67-watt traffic signal lamp has been developed and made available. Though consuming slightly more power for an equivalent light output, its life has been considerably extended.

Section 171.—Visibility and Shielding of Lens

Each lens, reflector, and visor shall be of such design as to render the signal indication, when illuminated, clearly visible to the traffic controlled by that face at all distances from 10 to 300 feet, under all light and atmospheric conditions except dense fog.

Each signal face shall, to the extent practicable, be so shielded by visors or hoods that an approaching driver can see only the signal indications intended for his observation.

Confusion results if signals are so located that operators see two signal faces giving different indications. Irregular street design frequently necessitates so placing signals that there is a comparatively small angle between their beams. Such cases require especial care in shielding so that the driver will be sure which signal he is to obey.

Shielding also reduces the tendency of drivers who see the yellow indication on the cross street to "jump" the Go indication.

Section 172.—Auxiliary Illuminated Signs

Signal heads and auxiliary mounting equipment should be designed so that auxiliary signs can be attached and illuminated either above, below, or on either side of any signal face.

Section 173.—Number of Signal Faces

In rural areas there shall be one or more signal faces visible to traffic on each approach to the intersection, except in those cases where the minimum pedestrian volume warrant is met, when a minimum of two faces shall be used for each approach.

In urban areas there shall be two or more signal faces visible to traffic on each approach to the intersection.

The advantages of having at least two faces for each approach roadway are believed sufficient to warrant making this a general requirement in urban areas. Trucks and busses very frequently obscure one-face installations, leaving the drivers of vehicles immediately behind uncertain of the signal indication as they approach. Two properly located faces will, at practically all intersections, provide drivers with a signal indication sufficiently in advance to insure their proper reaction to conditions at the intersection. High speeds and other traffic considerations will frequently warrant the use of two signal faces even in rural areas.

The advantage to pedestrians alone justifies the installation of two signal faces at many locations, since it provides indications within reasonable range of the normal line of sight for all persons on foot. If one of the signal faces is to be on the near side, however, a total of three faces will be needed to provide adequate pedestrian indications. Satisfactory enforcement of pedestrian regulations is difficult unless signal faces are clearly visible for all lines of pedestrian movement.

Section 174.—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 an uncertain and hazardous practice. Under such conditions, drivers on cross streets at nonsignalized intersections must often enter the cross walk to see a signal indication on the main street. Strangers are likely to enter nonsignalized intersections unknowingly, which is obviously hazardous.

Section 175.—Location of Signal Faces at Intersections

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 signals are installed on the basis of the pedestrian volume warrant, or where the pedestrian volume warrant is equalled or exceeded, a vehicle or pedestrian signal face shall be installed at the far end of each cross walk.

One of the more controversial points in the standardization of traffic signal practice has been the matter of signal-face location at intersections. The advantages of far-side, near-side, mast-arm, and center-suspended locations have been sufficient to induce the choice of all these locations for various types of situations, despite a definite endorsement in the previous manual of the far-right-corner location. When asked in a recent poll to express their preference as to signal location, a group of 56 outstanding traffic engineers could not develop a majority for their first choice for either rural or urban intersections, although the greatest number of votes was cast for the center-suspended location in rural areas and for the far-right—far-left location in urban areas.

Because of the diversity in practice and the lack of agreement among qualified engineers on signal location, the above requirement does not specifically fix the points of signal placement. Instead, the engineer is held responsible for a study of the visibility conditions on each intersection approach and the subsequent positioning of a signal indication conspicuously within the normal line of view of drivers and pedestrians using the intersection. Although this individualized selection of signal location seems the most desirable, undue variation in location from intersection to intersection along the same street is to be avoided, as this may create confusion and hazard.

The need for pedestrians to have a signal indication directly before them while proceeding through the intersection area suggests the advisability of having signal faces at the far side of the intersection. With all far-corner signals, two signal faces per corner will provide a signal at the end of each pedestrian cross walk, whereas three signal faces per corner are needed to accomplish the same results with a signal on the near-right corner. (See sketches in fig. 22.)

The near-side location has merit in that the signal can be placed at or near the Stop line, the point of obedience. The near-side location, in a general way, is also more consistent with uniform positions with respect to the approach lanes than is the far side, especially where irregular types and forms of intersections are involved.

The trend toward the use of signals suspended directly over the traveled way, either on mast arms or on a span wire, has been increasing in recent years. This location is especially effective at rural intersections where speeds are high and maximum prominence for signal indications to drivers is needed. Another factor contributing toward more frequent use of over-the-roadway signals is the growth
in brilliance and color of illuminated advertising signs in shopping areas. Where such background lighting is likely to be a serious hindrance to the effective display of traffic signal indications, consideration should be given to the mast-arm or suspended location for at least one of the signal-face locations.

Pedestals in the roadway to carry signals are driving hazards and are not recommended, despite their obvious advantage as conspicuous signal locations. This is not intended, however, to preclude the use of signals on pedestals or posts within the area of properly designed channelizing islands or in the median strip of divided roadways.

Where physical conditions prevent a vehicle driver from having a continuous view of at least one signal indication through the 300 feet immediately in advance of 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 300 feet, a caution signal (sec. 278) or a Signals Ahead sign (sec. 70) shall be erected in a suitable position to warn approaching traffic.

Section 176.—Height of Signal Faces

The bottom of the housing of a signal face shall be not less than 8 feet nor more than 10 feet above the sidewalk or, if none, above the pavement grade of the center of the highway, except that where vehicles must pass under a signal housing, the height to the bottom of the housing shall be at least 14½ feet but not more than 15½ feet above the roadway surface.

Maximum visibility is the guiding principle in deciding signal height. Signal faces should be high enough not to be obstructed unnecessarily by passing vehicles and pedestrians. On the other hand, especially in urban territory, the signal faces should be low enough to be within easy range of the average pedestrian’s and waiting motorist’s eyes. Grades on approaching streets may be important factors in determining the most effective height.

The clearance required for signal housings mounted over the roadway is consistent with general highway requirements for overhead structures.

Section 177.—Pointing of Signal Faces

Each signal face shall be so adjusted vertically and horizontally that its beams will be of maximum effectiveness to the approaching traffic for which it is intended.

In general, signals should be pointed so as to have a maximum effectiveness in the usual position of approaching drivers at a distance from the Stop line equal to the average distance they would move while reacting to the Stop indication and stopping their vehicles. The influence of curves or grades should also be considered in the aiming of signals.

For an average urban intersection where the normal speed of approaching traffic is 25 miles per hour, the point of maximum effectiveness for aiming the signal would be at the height of a driver’s eyes, about 6 feet to the right of the center line of the pavement and about 75 feet back from the Stop line.

Frequently poles on which signal faces are installed are not exactly vertical. Brackets or other mounting fixtures used should be of such a
design that it will be possible to adjust the signal face both horizontally and vertically through a considerable angle.

Section 178.—Location in Relation to Curb Line

Signal faces mounted at the roadside shall be located as near as practicable to the curb line of the street whose traffic they control. They should be about 3 feet from the cross walk of the intersecting street, or from the place where a cross walk would normally be located. A signal or its support should not obstruct the cross walk.

In order to present to the driver a maximum of effectiveness, a post or bracket mounted signal face should be kept close to the curb line. However, for the protection of the equipment from damage by passing vehicles, it is not desirable that any part of the signal head extend within 1 foot of the curb line.

Section 179.—Location in Relation to the Pavement or Traveled Surface

Regardless of the street or highway cross-section design, a signal face shall not be more than 10 feet to the right of the pavement or traveled surface.

In the case of rural highways, the shoulder width may create a problem in signal location. So long as the signal face is not more than 10 feet to the right of the pavement and is not hidden by foliage or other sight obstructions, it should be satisfactorily visible. Experience indicates that signals mounted on posts near the curb in urban areas are generally effective although, with parking at the curb, the right side of approaching vehicles is normally about 12 feet laterally from such signals, which roughly corresponds with the distance specified above as a maximum. The vehicle operator usually gives his major attention straight ahead and a signal indication more than 10 feet from the edge of the moving lane is not likely to receive proper attention.

This rule has important bearing on both first cost and maintenance outlay, for if a signal can be post-mounted within 10 feet of the improved surface, the advantages of low mounting height and simplified maintenance result. However, if the shoulder width or some similar condition requires that a mast-arm-mounted signal or a center-suspended signal be used, costs are increased, mounting height is greater, and maintenance is more difficult.

Section 180.—Removal of Confusing Advertising Lights

Act V of the Uniform Vehicle Code (sec. 37) 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 of a color and location similar to traffic control signals. The steps necessary to eliminate this sort of hazard are warranted.

Section 181.—Provision for Future Installation

Signals should always be installed so that future traffic growth and other later requirements can be as readily met as possible. Outmoded, worn-out equipment and materials constitute serious handicaps to extension or improvement of existing signal systems. The type of mounting selected, the choice of wiring and accessory equipment, and other seemingly minor details of a signal installation play an important part in the reliability and effectiveness of signal operation during their service period. These elements should be carefully chosen for the particular duty they are intended to perform, and with a view toward obtaining uniformity and standardization of equipment, so that exchange and replacement operations will be simplified.

Section 182.—Types of Mounting for Signal Heads

Types of signal-head mountings include the following:

1. Alongside the roadway:
   a. Posts 6 to 10 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.

Group 1 has many advantages, including simplicity of design, ease of access and maintenance, and better conformity in height to the needs of traffic. Of the two types in this group, post mountings are preferable. Where an existing pole is at the position desired for the signal faces, however, it is generally used. New poles may be installed to provide necessary support and clearance for overhead cable.

Mast-arm and cable suspension involve considerable lateral strain. Cable suspension may interfere with fire fighting and requires overhead maintenance equipment. Both of these types involve difficulties in cleaning and maintenance, besides placing the signals too high for best visibility to waiting traffic and to operators of vehicles close to the intersection. Suspended signals are desirable, however, at locations where side-mounted signals are apt to be overlooked, as at isolated rural intersections, 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. To improve the effectiveness of the signal indications to waiting vehicles and pedestrians, post-mounted signals may be used to supplement overhead installations at such locations.

Signals on posts or pedestals on islands are justifiable only in certain large, channelized, or irregular intersections. Under these conditions, the signals should be well protected by properly designed islands and signs and by night illumination.

Any mounting should be substantially constructed, with a strong foundation, preferably concrete, and should be able to withstand all weather conditions.

Section 183.—Installation of Underground Conduit or Cable

Underground conduit or cable, though considerably more expensive than overhead wiring, is generally preferable, especially for urban intersections. In certain zones it may be legally required. Before the underground wiring is installed, governmental units and utilities that may have underground structures or facilities at the location or may later place them there should be consulted. Much trouble and possible damages may thus be avoided. Furthermore, such organizations can give valuable advice as to how such work should best be done.

A large proportion of the cost of underground installations can be avoided if traffic control conduits are installed when the intersection or
signal location is torn up for some other purpose, such as for paving, repairing, or utility underground installations. Local authorities should anticipate future signal requirements and take advantage of any such opportunities to install conduit, even if such installation is in advance of the need. Though conduit is normally used, direct burial or “parkway” cable has also been employed successfully.

Section 184.—Selection of Cable

The cable is an important element in the successful and economical operation of a signal system.

Quality.—Experience has proved the desirability of using cable of high quality for all but purely temporary installations.

Some good traffic signal cable specifications (for use on 110–120 volt systems) call for a 600-volt cable with at least three sixtieths of an inch of 10 percent para rubber insulation and good quality cloth-braid covering on each conductor and with a cable covering suitable for the intended use of the cable. Developments of the last few years have provided several other satisfactory types of cable, for which specifications are obtainable from cable manufacturers. No. 12 or No. 14 B. & S. gage wire is often used at intersections. The size of conductor required for a master control cable in a coordinated system should be computed.

Color code.—A standard color code should be adopted for traffic control cables. Such a code identifies each conductor with a particular color or combination of colors in its braid covering, according to the function served by that conductor.

The advantages of a standard color code are considerable. Any person familiar with the color code can install, test, or replace controllers quickly because the function accompanying each color scheme is known. Color coding generally eliminates the need of tagging the leads. One of the difficulties with tags or numbered bands is that they are likely to come off.

Spares.—It is generally sound economy to provide several spare conductors in each local interconnecting and master control cable. From time to time, for one reason or another, conductors in a cable may develop defects and be no longer suitable for use. In such cases, the provision of spare conductors eliminates the cost of locating the trouble and making repairs, or of installing new cable. Spare conductors also permit adding new features, such as a pedestrian clearance period, or an illuminated sign.

Section 185.—Insulation of Cable

Adequate cable insulation shall be provided throughout the entire installation, conforming to fire underwriters' specifications.

Section 186.—Cable Positions and Clearances

Positions for traffic control cables shall be such as not to interfere with utility structures and wires or with positions reserved for them. Suitable clearances agreed upon by all interested parties shall be provided in all cases.

In most communities the utility companies and appropriate governmental agencies have agreed upon certain positions on poles and certain positions underground for various structures, conduits, and wires.

Much trouble can be avoided if those in charge of traffic signal installation will consult with the affected groups concerning location problems. Where a pole is used for several types of cable it is most important to maintain clearances satisfactory to all parties involved.

Section 187.—Messenger Wires

All overhead cable shall be supported by a suitable aerial messenger wire whenever there is a span of more than 30 feet.

The use of aerial messenger wire in such cases removes the strain from signal cables, and reduces the likelihood of cable trouble. Unsupported cable is apt to develop trouble at the ends of cable spans.

It is good economy to provide high-grade aerial messenger wire, such as that with a copper covering welded to the steel by the molten welding process. The size and strength of messenger wire depends on the load to be carried, but five-sixteens-inch wire with an ultimate strength of not less than 6,200 pounds is usually satisfactory for a 12-conductor signal cable.

Section 188.—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 herein 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 flashing device, the signal should be operated as a flashing device in accordance with recommendations in sections 208–210 and 279.

During season 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.

Section 189.—Length of Cycle

Considerable dissatisfaction with traffic signals may be attributed to improper timing and selection of cycle length. It is important, therefore, that the predetermined and constant cycle length for fixed-time signals be accurately related to traffic requirements. The cycles of traffic-actuated signals, on the other hand, vary and tend to adjust themselves to the demands of traffic. In this case, the total cycle length is partly or wholly dependent on adjustment of those time controls or cycle components that regulate the reaction of the signal-timing mechanism to vehicle or pedestrian actuations. Of course, the correct adjustment of these time controls ranks in importance with the selection of a proper cycle length for fixed-time signals.

The cycle shall be as short as will accommodate the necessary movements.

Short cycles encourage observance of the signals by pedestrians and vehicle drivers. Unfortunately, no entirely satisfactory formula are as yet available for an exact determination of proper cycle length.
For city conditions, a cycle length of from 35 to 50 seconds is generally satisfactory for the usual intersection. Rural intersections, heavy traffic volumes, or complex control problems may make it desirable to use somewhat longer cycles.

Changes in cycle length for different traffic conditions during the day, while requiring special equipment, are oftentimes justified.

Section 190.—Number of Traffic Phases

The number of traffic phases or group movements of vehicles and pedestrians required to obtain proper and efficient operation at an intersection varies with the composition and direction of the traffic flows as well as with the number of entering streets and the general intersection lay-out. A two-phase cycle in which the right-of-way is successively assigned to all movements on one street and then to all movements on the other will suffice for the majority of intersections involving two streets. Intersections having a large and concentrated volume of left turns or unusually heavy pedestrian movements, and those with more than four entering traffic streams, however, will frequently require a division of the total time cycle into three or more phases or grouped traffic movements in order to eliminate major conflicts between vehicles or between vehicles and pedestrians.

The traffic information collected should be most carefully studied for all intersections where the above-named conditions exist, with a view toward keeping the number of phases to a minimum consistent with needs. In determining whether a given intersection should be operated on two-, three-, four-, or multi-phase control, it should be kept in mind that certain unavoidable delays are added as each additional phase is introduced. Where one street carries a low volume of traffic and it is evident from the physical lay-out and the traffic pattern that more than two phases are needed, it is often possible to assign one Go or movement period to the low volume street while the other streets are given two such Go periods.

Section 191.—Rotation of Intervals

Each interval provided for traffic movement should generally be given once and only once during each cycle, but extraordinary conditions may warrant the duplication of an interval in any one cycle. With certain types of traffic-actuated control equipment, it is possible to omit from the cycle those traffic movements for which no demand has been registered. It should be understood that the movement of one particular line of traffic may continue during several intervals. No special indication or interval should be used in a signal cycle until its need has been definitely established by traffic counts and observation.

Following are typical illustrations of the sequence of intervals in simple cycles:

### Simple Cycle Without Pedestrian Interval

<table>
<thead>
<tr>
<th>Interval number</th>
<th>Main street</th>
<th>Cross street</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Red</td>
<td>Red</td>
</tr>
<tr>
<td>2</td>
<td>Red</td>
<td>Red</td>
</tr>
<tr>
<td>3</td>
<td>Yellow</td>
<td>Yellow</td>
</tr>
<tr>
<td>4</td>
<td>Red</td>
<td>Yellow</td>
</tr>
</tbody>
</table>

and repeat.

### Simple Cycle With Combination Pedestrian Interval

<table>
<thead>
<tr>
<th>Interval number</th>
<th>Vehicles</th>
<th>Pedestrians</th>
<th>Cross street</th>
<th>Vehicles</th>
<th>Pedestrians</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Green</td>
<td>WALK</td>
<td>Red</td>
<td>Red</td>
<td>WALK</td>
</tr>
<tr>
<td>2</td>
<td>Green</td>
<td>WALK</td>
<td>Red</td>
<td>Red</td>
<td>WALK</td>
</tr>
<tr>
<td>3</td>
<td>Yellow</td>
<td>WALK</td>
<td>Green</td>
<td>Red</td>
<td>WALK</td>
</tr>
<tr>
<td>4</td>
<td>Red</td>
<td>WALK</td>
<td>Red</td>
<td>Green</td>
<td>WALK</td>
</tr>
<tr>
<td>5</td>
<td>Red</td>
<td>WALK</td>
<td>Red</td>
<td>Green</td>
<td>WALK</td>
</tr>
<tr>
<td>6</td>
<td>Red</td>
<td>WALK</td>
<td>Yellow</td>
<td>Red</td>
<td>WALK</td>
</tr>
</tbody>
</table>

and repeat.

### Section 192—Traffic Movement Intervals Proportioned to Traffic Requirements

Cycles should be divided into intervals proportionate to the time required by the traffic which will enter the intersection during the signal intervals. Where time requirements of the different movements vary widely during different hours of the day, provision should be made for changing the percentage of the total cycle allowed for each interval to accord reasonably well with these requirements. Where the time requirements of the different movements do not vary materially during the day, the percentages allowed the different intervals should normally be those that most accurately accord with the requirements during the heaviest traffic hour.

Traffic moves in lanes, and the more lanes in use, the shorter is the time required for a given volume to pass through an intersection, assuming that the intersection has adequate discharge capacity. Intervals should not, therefore, be proportioned purely on the basis of relative volumes entering in the different directions unless there is the same number of moving lanes on each entering street. Even then, streets carrying considerable proportions of slow-moving vehicles, or streetcars and busses which must load and unload at intersections, will require more time to discharge a given volume than streets where the traffic is made up largely of passenger automobiles. Adjustment for such differences will often be necessary.

Traffic frequently distributes itself among the available lanes so that each lane requires approximately the same time to discharge its load. Under certain conditions, however, this may not be true. A given lane, because of turning movements, the presence of commercial vehicles, or other factors, may require a greater amount of time than others. This then becomes the critical lane and should be the one considered in proportioning intervals. Usually the volume of traffic per lane entering the intersection on a Go interval will not be equal from the two directions on the same street. The per-lane volume of traffic entering from the heavier direction, therefore, should generally determine the time required for the interval.

### Section 193—Unexpected Conflicts During Go Interval

No movement which may involve an unexpected crossing of pathways of moving traffic should be permitted during any Go 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. Traffic subjected to the unexpected conflict is effectively warned thereof.
When such conditions of possible unexpected conflict exist, warning may be given by an illuminated sign or, under certain conditions, by the use of a flashing signal instead of a green Go signal. The foregoing applies to vehicle-pedestrian conflicts as well as to vehicle-vehicle conflicts.

Section 194.—Vehicle-Clearance Interval

A yellow vehicle-clearance interval shall be used following each green interval. In no case shall a yellow interval be displayed in conjunction with the change from red to green.

In general, the vehicle-clearance interval should be not less than 3 seconds, nor more than is reasonably necessary to clear the intersection of traffic. At intersections where approach speeds are 35 miles per hour or more the clearance interval on the street or streets having this approach speed should usually be at least 5 seconds.

While clearance intervals longer than 3 seconds may occasionally be necessary at very wide intersections or under other unusual conditions, they are apt to cause impatience among drivers awaiting the signal change and consequent starting before the green indication appears.

Theoretically, the display of yellow after red has the effect of advising the waiting motorist to prepare to start. In practice, it has frequently induced waiting drivers to start forward in advance of the green indication.

The use of the yellow clearance interval as a period during which pedestrians are supposed to walk is disapproved. The functions of the yellow interval should be exclusively those of warning approaching drivers and clearing the intersection.

Some authorities feel that a short all-way red interval of about 3 seconds’ duration immediately after the normal yellow clearance interval has merit at some intersections in that it provides a brief additional clearance period which permits the slower moving pedestrian to complete his crossing without vehicle interference.

Section 195.—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.

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 herein are intended to provide the essential features for an adequate maintenance program.

Section 196.—Signal Lamp Replacement

Burned-out signal lamps convert traffic signals to the role of a traffic hazard. Immediate replacement of such lamps, or scheduled replacement of lamps short of their anticipated life, is an extremely important maintenance function.

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

1. Theory of probabilities of lamp failure as applied to mass production and manufacturer’s rating.
2. The effect of differences between socket and rated voltage.
3. Failure due to vibration and handling.

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

Section 197.—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. A signal located on a bridge over railroad tracks may require cleaning once a month.

Section 198.—Maintenance of Controllers

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

Lubrication.—Controllers shall be carefully lubricated, in accordance with a lubrication chart furnished by the manufacturer, at least as frequently as is specified by the manufacturer and more frequently if experience proves it necessary.

Different controllers often require lubrication at widely different intervals.

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.

The checking as to timing can be done effectively in connection with cleaning, lubrication, or overhauling. 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 housing.

The necessity for checking timing arises from the possibility of mechanical or electrical misadjustments or unauthorized changes in timing.

Section 199.—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, and other conditions.
Section 200.—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 aid in determining whether or not the maintenance program 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 and for each specific controller.

C—COMPARISON OF FIXED-TIME AND TRAFFIC-ACTUATED CONTROL

Section 201.—Relative Adaptable to Normal Intersection Requirements

Each of the two principal types of traffic signal control, fixed-time 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 of the two types to the particular requirements at the location proposed for signalization. While fixed-time control has had by far the wider application up to the present and will very likely continue as the more popular choice for reasons which will be discussed later, the use of traffic-actuated control for certain situations is increasing. The following discussion is intended to bring out the basic differences in the two types of control, insofar as their operating characteristics and suitability for various traffic requirements are concerned.

With fixed-time control, a consistent and regularly repeated sequence of signal indications is given to traffic. The total cycle length, or time required for one complete sequence of signal indications, is a feature of fixed-time control which can usually be adjusted from a minimum of 20 seconds to a maximum of about 120 seconds. A cycle length is selected, based on the traffic demand, and divided into the intervals necessary for handling that traffic. Signal indications then appear in accordance with the predetermined sequence unless changed to other timing schedules by automatic or manual means.

This regularity of timing is both an advantage and a handicap. It permits maintenance of an established time relation with other signals in the area so that vehicles can move through the signalized intersections with a minimum of delay. It does not, however, recognize the short-time variations in traffic flow. In most cases, this means excess or wasted time when cars on one street are required to wait for a signal change although there is no traffic using the other street. These time losses are small but when they occur frequently may cause considerable delay, inconvenience, and reduction in intersection capacity.

With the traffic-actuated type of control, the cycle length is not predetermined or fixed at any definite value. Similarly, the intervals are usually self-adjusting within certain limits so that they more accurately fit the needs of traffic. The sequence of intervals normally remains the same, but the time for a complete rotation or sequence of intervals will vary widely. This type of control has a considerable measure of flexibility and some of the time and capacity losses inherent in fixed-time control are automatically avoided. This is especially true at intersections where the traffic load shifts from one street to the other during the period of signal operation. Because of the flexibility characteristic of traffic-actuated control, its principal application has been at locations not interconnected with other signalized intersections for progressive traffic movement.

Many operating variations are possible with traffic-actuated control. Intersections may have semi-traffic-actuated or full traffic-actuated control. In the former case, the right-of-way or green signal is normally given to the major street unless a side-street signal is received, at which time the right-of-way will be temporarily assigned to the side street. This type of control equipment has its principal application at isolated signal locations where traffic on the cross street or route is light and arrives at irregular intervals but, unless aided by signals, is unable to enter and cross the principal route safely without long waiting periods. With full traffic-actuated control, vehicles on all approaches affect the operation of the signal and the assignment of right-of-way is made substantially in accordance with the demands on the several approaches. Complicated intersections often require this type of control to permit a reasonable degree of operating efficiency to be attained.

Section 202.—Special Merits of Fixed-Time Control

Fixed-time control is, as previously mentioned, the more commonly used of the two types of equipment. This is due largely to (1) the simplicity of the equipment, (2) the fact that it provides positive speed control in a signal system, and (3) at many intersections it does an adequate job in controlling intersection traffic. The fixed-time type of control, if carefully timed, can approach very closely the efficiency of traffic-actuated control at intersections where movements are well balanced by direction and where traffic volumes do not vary widely during the day. The equipment is also more easily serviced and maintained than the more complex circuits of the traffic-actuated controller. The constancy of the cycle length is of obvious advantage when signals are interconnected for obtaining progressive movement and centralization control.

Certain additional flexibilities available in fixed-time control permit the use of a different time cycle, cycle division, or offset to meet more precisely the requirements of traffic during the peak and off-peak hours. This change in timing each day may be regular or on a differing program, depending on the requirements encountered. Such programmed control timing is of considerable value and makes for more efficient handling of intersection and system requirements.

Section 203.—Special Merits of Traffic-Actuated Control

The volume of traffic approaching most intersections is a continuously and often widely fluctuating quantity. Maximum efficiency in signalized intersection control is obtained when the signal indications are timed so as to reduce to a minimum the delay to traffic using the intersection.

To approach this condition as closely as possible, control mechan-
isms must be able to regulate the signals in accordance with changing demands of traffic. Means must therefore be provided for detecting the presence and volume of traffic, both vehicular and pedestrian, in the approaches to the intersection; and the controller must be able to apportion right-of-way time with maximum effectiveness.

Traffic-actuated control signals operate upon this demand principle. There are two general types of traffic-actuated control: (1) semi-traffic-actuated control, in which traffic-actuation devices are installed in only some of the approaches; and (2) full traffic-actuated control, in which such devices are provided in all approaches to the intersection.

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

1. Delay and inconvenience are not great at traffic-actuated controlled intersections because traffic is passed through the intersection in a manner closer to approximating the natural approach pattern. Any reduction of delay operates to increase the capacity of the intersection.

2. Traffic-actuated control is especially effective at multiple intersections, or at intersections with traffic requirements that vary considerably during different times of the day.

3. For problem locations in progressive systems, traffic-actuated equipment will usually handle traffic conflicting movements more expeditiously than fixed-time equipment, particularly if these special movements vary in time requirements at different hours.

4. The full service advantages of continuous Stop-and-Go operation during low volume periods are retained with traffic-actuated control, whereas fixed-time signals often are switched to flashing operation under these conditions to avoid excessive delay in traffic.

5. Traffic-actuated control may, in some instances, minimize the tendency of traffic to avoid signalized intersections, and thus result in the use of more logical routings.

Section 204.—Other Factors Governing Selection of Type of Control

When the problem of choosing between fixed-time and traffic-actuated control equipment is presented, the factor of cost has often been a decisive one. Mainly because of the need for installing detectors in or adjacent to the roadway and the more complex timing circuit in the controller, traffic-actuated signal installations are considerably more expensive than most fixed-time control installations. Due to the wide range in types of fixed-time and traffic-actuated equipment it is not possible to state comparative costs with any exactness, but the more complex types of fixed-time control are the only ones that approach the cost of the simplest traffic-actuated controls. It is most important, therefore, that a careful study be made of the intersection requirements to determine which type of control will be the more appropriate.

If investigations show that the physical lay-out of the intersection presents no unusual difficulties, that traffic is of substantial volume and reasonably well balanced by direction on both streets and does not change its time requirements too greatly throughout the day, and that no severe pedestrian or turning-movement problems exist, it is likely that fixed-time or traffic-actuated control would be almost equally satisfactory. If the location is close to another signal with which it may now or at some future time be desired to make interconnection for progressive movement of traffic, the fixed-time installation will probably be preferable. However, in instances where the intersection is quite isolated from other signalized intersections, with no interconnec-

Section 205.—Definition

A fixed-time signal is a traffic control signal by which traffic is alternately commanded to stop and permitted to proceed in accordance with a predetermined time schedule.

Section 206.—Advance Engineering Data Required

The installation of fixed-time signals at intersections should be preceded by a thorough study of traffic, roadway, and accident conditions. Among the facts that should be obtained are the following:

1. Complete vehicle volume counts, including right and left turns and classification by vehicle type. These counts should include the periods in a typical day when the signal would appear to be most needed, and in all cases should be at least 8 hours in duration.

2. Pedestrian volume counts on each cross walk during the same periods as the vehicle counts.

3. Speed and classification of vehicles on approaches to the intersection.

4. Details of the physical lay-out, such as roadway width, channelization, grades on approaches, corner sight-distance restrictions, bus-stop locations, parking practice, and location of railroad grade crossings. These data are of most value when assembled on a condition diagram, such as is shown in figure 24.

5. A summary of accidents by type, location, vehicle or pedestrian direction, time, etc. A collision diagram covering a year or more of accident experience should be prepared from this information. A typical collision diagram appears in figure 24.

Section 207.—Warrants for Fixed-Time Signals

With such information as will be provided by the above studies, it is possible to appraise the need for signalization in terms of the warrants given below. If the warrant conditions stated are not satisfied and there still appears to be need for signal control, consideration should be given to the use of traffic-actuated equipment (see secs. 233–235 for a discussion of the application of this type of control). The warrants presented for fixed-time signals are intended primarily for typical intersections of two two-lane, two-way streets or highways.

In some cases separate values are given for city and rural locations, and in other instances the warrants are qualified for special problems such as those which arise at intersections near railroad grade cross-
ings, schools, industrial plants, stadiums, and similar points of public congregation.

Fixed-time traffic signals shall be installed and operated only where and when one or more of the following warrants, as defined in sections 208 to 213, exist:

1. Minimum vehicular volume.
2. Interruption of continuous traffic.
5. Accident hazard.
6. Combinations of 1 through 5—other factors.

Section 208.—Minimum Vehicular Volume

The minimum vehicular volume warrants are intended for application at locations where no special conditions exist and where the amount of intersecting traffic is the outstanding reason for intersection conflicts. As previously stated, the warrant values apply to the intersection of two two-lane, two-way streets or highways. Vehicle volume warrants for intersections of roadways having two or more moving lanes in one direction should be somewhat higher than the values given below. Obviously, more traffic can pass through an intersection in a given time in two or three lanes than in one lane.

The minimum vehicular volume warrants are as follows:

In urban areas:
1. Total vehicular volume entering the intersection from all approaches must average at least 750 vehicles per hour for any 8 hours of an average day, and
2. Total vehicular volume entering the intersection from the minor streets must average at least 175 vehicles per hour for the same 8 hours.

In rural areas:
1. Total vehicular volume entering the intersection from all approaches must average at least 500 vehicles per hour for any 8 hours of an average day, and
2. Total vehicular volume entering the intersection from the minor highway or highways must average at least 125 vehicles per hour for the same 8 hours.

On important rural highways, traffic during the highest 8 hours of the average day will usually amount to one-half to two-thirds of the 24-hour total. This means that a total of 6,000 to 8,000 vehicles entering the intersection on an average day is the approximate equivalent of the minimum vehicular volume warrant stated above for rural areas. Peak traffic on summer holidays and Sundays may frequently be twice as high as these values and for approximately half the days of the year the volumes will exceed the stated average of 6,000 to 8,000 vehicles per day.

Recognition of these relationships is most important if the warrants are to be properly interpreted. A signal installation cannot be considered justified under the minimum vehicular volume warrant unless the volumes are recorded on or adjusted to a day reasonably representative of the average condition under which the signal is to be operated.

On urban streets, traffic during the highest 8 hours of the average day is a somewhat more variable percentage of the 24-hour volume than is found on important rural highways. The range of one-half to two-thirds of the total 24-hour volume will nevertheless include a large proportion of the city traffic patterns for average weekdays, which is the time when signals will be of most use. Applied to the

* See page 104 for distinction between urban and rural areas.
urban area warrant stated above, this means that the minimum total vehicular volume entering city intersections must ordinarily be from 9,000 to 12,000 vehicles on an average day, of which total approximately one-fourth must be side-street traffic, before signal installation on the basis of this particular warrant would be justified.

From studies made at isolated signalized intersections, principally in cities, it appears that the peak hour will often be as much as 50 percent higher than the average of the 8 highest hours during the day. Selection of the 8-hour volume warrant period (not necessarily 8 consecutive hours) is based on the knowledge that heavy traffic flows of shorter duration in effect include only morning and evening rush-hour traffic at many locations, which might be better handled by traffic-actuated equipment or by officer control. It is also obvious that a count of 8 hours provides a more reliable measure of need than do shorter period counts.

Regardless of the general warrant stated above, traffic signals should not, if avoidable, be installed at a street or highway intersection near a railroad grade crossing. Traffic signals too close to railroad grade crossings are likely to be misinterpreted by some drivers as governing the periods when it is safe to cross the railroad tracks. If the grade crossing is also protected by standard train-approach signals, there may be considerable confusion between the two types of signal apparatus so close together.

If, however, the minimum vehicle volume warrant is satisfied at an intersection within 200 feet of a railroad grade crossing and if, without signals, traffic is likely to be retarded and vehicles forced to stop on the tracks, a signal installation may be warranted. This type of installation is regarded as exceptional, and extreme care should be taken in all matters relating to the layout, design, and operation to avoid the possibility of forcing vehicular traffic to stop on the crossing. To accomplish this, there should normally be an auxiliary control signal at the railroad crossing to stop traffic approaching the intersection from the railroad side when the intersection signal shows a Stop indication and when trains are approaching and crossing the highway. If standard train-approach signals are employed at the crossing, their operation should be positively coordinated with the intersection signal to prevent any possibility of forcing vehicular traffic to stop on the tracks when a train is approaching.

Similarly, coordination of the crossing and intersection signals may be required for traffic moving away from the intersection so as to avoid undue blocking of traffic movement parallel with the railroad while trains are approaching or are on the crossing.

When for a period of two or more consecutive hours the total vehicular volume entering an intersection having fixed-time signals installed under this warrant falls below 50 percent of the minimum volumes stated above for urban and rural intersections, flashing operation shall be substituted for fixed-time operation for the duration of such periods of reduced volume.

In many of the medium and smaller sized communities, a change to flashing operation will frequently be warranted by 8 or 9 p.m. on an ordinary evening. The impracticability of changing the method of operation many times during the day is recognized and therefore it is recommended that flashing operation be limited to not more than three periods in 24 hours.

Section 209.—Interruption of Continuous Traffic

Vehicles on through streets or highways tend, if uncontrolled, to travel through minor street intersections at speeds that make it difficult and hazardous for vehicles and pedestrians from the side street to cross or enter the principal traffic stream, despite laws that require such vehicles on the highway to yield the right-of-way to cross traffic under certain conditions. Where cross traffic suffers undue delay or hazard because of this condition, a signal installation may correct the condition. If several intersections in the same vicinity are similarly affected, a speed-controlling, progressive signal system may be a suitable remedy. However, if such a system is installed, it is generally undesirable to have signalized intersections more than 1,200 feet apart.

Minimum warrants for interruption of continuous traffic are as follows:

In urban areas:

1. At an intersection on an important street, the vehicle volume along that principal street must average at least 750 vehicles per hour for any 8 hours of an average day; and

2. The combined vehicle and pedestrian volume from the side street or streets must average at least 75 units per hour for the same 8 hours; and

3. The average* vehicle speed must exceed 20 miles per hour on the principal street approaches to the intersection.

In rural areas:

1. At an intersection on an important highway, the vehicle volume along that principal highway must average at least 500 vehicles per hour for any 8 hours of an average day; and

2. The combined vehicle and pedestrian volume from the side highway or highways must average at least 50 units per hour for the same 8 hours; and

3. The average* vehicle speed must exceed 35 miles per hour on the principal highway approaches to the intersection.

In addition to the above-described conditions warranting signal installation, there are similar instances where traffic signals can provide a genuine service over a somewhat shorter period of time. Industrial plants, resorts, stadiums, and other places where large volumes of traffic are found on regular and reasonably frequent occasions are examples. For this special purpose, there are presented below a series of additional warrants for the interruption of continuous traffic, any one of which may justify signal installation:

In urban areas:

1. Vehicular volume on the major thoroughfare past an establishment of the type mentioned above exceeds 800 cars per hour at the approximate time of major movement of traffic to and from the establishment, and traffic to or from the establishment roadway during the same period of time meets one of the following warrants:

   (a) A minimum of 800 cars per hour, or
   (b) A minimum of 200 pedestrians crossing per hour, or
   (c) A minimum of 200 cars and 100 pedestrians crossing per hour.

2. Along any streets of 40 miles per hour or more during major movement of traffic.

3. Four lanes of traffic moving past the establishment exceed an average speed of 40 miles per hour during major movement of traffic.

4. A sharp vertical or horizontal curve or view obstruction exists near the entrance or exit of the establishment, or one or a combination of which creates a serious accident hazard.

*This is the arithmetical average of a representative sample of observed speeds of traffic approaching the intersection when there is no signal, stop sign, or other control feature affecting the measured speeds. The determination of speeds of vehicles approaching intersections should be made for a relatively short distance (say 30 feet) ending at the stop line, or a location corresponding thereto.
In rural areas:

Warrants for establishments located in rural areas are 50 percent of the foregoing traffic volumes for major thoroughfare and establishment entrance or exit.

When for a period of two or more consecutive hours the vehicle volume on the principal thoroughfare or the combined vehicle and pedestrian volume from the side street or highway falls below 50 percent of the minimum volume stated above for urban and rural intersections, flashing operation shall be substituted for fixed-time operation for the duration of such periods of reduced volume.

Section 210.—Minimum Pedestrian Volume

Provision for safe and convenient crossing of roadways by pedestrians deserves greater attention than it has heretofore received. Nearly two-thirds of all persons killed in city traffic accidents and nearly half the persons killed in all traffic accidents in rural and urban areas combined are pedestrians. The criteria for installation of fixed-time signals on the basis of pedestrian volume are as follows:

In urban areas:

1. Pedestrian volume crossing the major street must average at least 250 persons per hour for any 8 hours of an average day; and
2. Vehicular traffic entering from the major street must average at least 600 vehicles per hour for the same 8 hours; and
3. The average vehicle speed must exceed 15 miles per hour on the approaches to the intersection.

In rural areas:

1. Pedestrian volume crossing the major highway must average at least 125 persons per hour for any 8 hours of an average day; and
2. Vehicular traffic entering from the major highway must average at least 300 vehicles per hour for the same 8 hours; and
3. The average vehicle speed must exceed 50 miles per hour on the approaches to the intersection.

When for two or more consecutive hours the vehicular and pedestrian traffic volume drops to 50 percent or less of the warrant values stated above, the signal shall not be operated as a fixed-time signal.

Traffic control signals may be warranted for pedestrian benefit in certain cases where vehicular volume is somewhat less than the warrant values but where vehicular speeds frequently exceed the warrants stated. Such a condition may create a serious traffic hazard. This case might be covered by the accident-hazard warrant described in section 215. At intersections where a pedestrian and vehicle conflict is the predominating factor in determining the need for signal control, special pedestrian signals may be justified. For a discussion of this subject, see section 270.

Conditions at certain nonintersection locations may be improved by the installation and operation of a traffic control signal for the benefit of pedestrians, especially if large numbers of pedestrians must cross roadways at irregular intervals. Such locations are in the vicinity of schools, large meeting places, and parks. Generally, such signals should either be of the pedestrian-actuated type or should be operated manually only during periods when they are needed. This type of application is covered more thoroughly in sections 269 to 276, which deal with special pedestrian signals.

Studies of pedestrian and vehicular movements are essential to determine whether pedestrian conditions justify the installation and operation of a traffic control signal. The pedestrian study should determine the number of pedestrians crossing each roadway in each direction separately. Persons going to or from a streetcar loading point across one or more moving traffic lanes should be counted. Pedestrian counts should cover at least those hours when it is believed that pedestrian volume crossing the major street may warrant traffic control operation.

To supplement pedestrian and vehicle counts at a given intersection, it is frequently desirable to make studies at other signalized intersections in the same area to determine the degree of driver and pedestrian observance of the signal indications. This should include a record of the percentage of pedestrians crossing the red indication, the percentage of drivers going through on the yellow or red indication, and especially those making unauthorized turns on the yellow or red indication. If the observance record is poor, it is likely that the value of a signal otherwise justified under this warrant will not materialize without the introduction of other measures designed to secure improved observance.

Section 211.—Coordinated Movement

A fixed-time signal may be warranted as a part of a coordinated signal system if a majority of the signalized intersections composing the system comply with one or more of the established warrants and if the proposed signal installation is necessary to maintain compact group movement or desired group speed. Coordinated control sometimes necessitates traffic signal installations at intersections where they would not otherwise be warranted, for effective regulation of speed and for maintenance of proper grouping of vehicles. By keeping the vehicles in a coordinated system in compact groups and effectively regulating their speed, less delay and greater convenience and safety are accorded both vehicles and pedestrians entering the coordinated roadway at intervening unsignalized intersections.

In general, additional signals for coordinated movement are not warranted if the distance between signalized intersections is already less than 1,200 feet. If there is a choice between intersections to be protected by signals to be installed under this warrant, there should be a careful analysis to determine which intersection most nearly justifies the signal installation under other warrants.

Since signal installations at intersections within 200 feet of a railroad grade crossing are to be avoided, it may be preferable to space signals in a coordinated system somewhat more than 1,200 feet apart in the vicinity of grade crossings. If a signal is needed near the crossing to maintain progression, extreme care should be used in selecting its location, design, and plan of operation so as to preclude the possibility of forcing vehicles to stop on the tracks under heavy traffic conditions.

In the application of coordinated signal systems, the question of desirability of installing "spacing signals" to maintain vehicle groupings will frequently arise. In studying the situation, vehicular volume counts as heretofore described should be made at all intersections where the data may be needed. These should be supplemented by observations of speeds of vehicles and the amounts and kinds of delay encountered in moving along the highway.
Section 212.—Accident Hazard

If none of the warrants except the accident-hazard warrant described below is fulfilled, the initial presumption should be against signalization. The installation of a traffic control signal because of a spectacular or much-publicized accident, or because of a small number of accidents, is strongly condemned. The full accident record of the location should be carefully investigated before any installations are made under this warrant. Such study and experience may show at once that the hazard existing cannot be corrected by a device less restrictive than a signal. In general, however, a fixed-time signal may be considered warranted only where:

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 $25 or more; and
3. There exists a volume of vehicular and pedestrian traffic not less than 50 percent of the requirements specified in the minimum vehicular volume warrant, the interruption of continuous traffic warrant, or the minimum pedestrian volume warrant.

Any fixed-time signal installed because of accident hazard should be operated on the shortest cycle length that will adequately serve traffic approaching during the heaviest traffic hour. Thorough analysis of accident experience in advance of making installation under this warrant is important. Accident history can usually be obtained from police accident records or from accident reports made by vehicle operators involved. Without a careful analysis of such records it is impossible to determine upon the most suitable remedial measures. The following four steps are very helpful in determining what should be done:

1. Analyze summarized statistics of all recorded accidents at the intersection.
2. Analyze physical characteristics at and near the intersection.
3. Analyze traffic flow characteristics.
4. Analyze the collision diagram.

A review of these data will frequently reveal a number of significant facts. For example, types of accidents have a very important bearing on the appropriateness of signalization. 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, 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, particularly if an independent time interval is allowed during the signal cycle for the left-turn movement.
4. Those involving excessive speed, in cases where speed 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 on the same go interval.
4. Other types of pedestrian accidents, if pedestrians do not obey the signals.

As an alternate to installing traffic signals arbitrarily at intersection locations that appear to be hazardous, it is desirable to institute, with proper education and enforcement, remedial measures which cause less delay and inconvenience to traffic. Warning, Advisory Speed, and Stop signs; marking of lanes or otherwise organizing traffic movements; pedestrian and traffic islands; fixed street or highway lighting; removal of view obstructions; and proper regulation of parking are examples. If studies indicate that one or a combination of these other remedial measures is adapted to conditions, it should be given a fair trial for at least 6 months, and preferably for a year. Following the trial period, a restudy should be made, and if satisfactory results have not been achieved, such additional steps be taken as are indicated by the study.

Section 213.—Combination of Warrants—Other Factors

Fixed-time 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, particularly if there are present other important factors, such as:

1. A sudden change from rural conditions, where relatively high speeds are safe, to those of an urban business district.
2. Extreme width of roadway which pedestrians must cross.
3. Predominance of especially handicapped pedestrians, such as small children or blind, aged, or crippled adults, who need to cross the roadway;
4. An intersection on or at the bottom of a long or steep grade.

In case 4, there should generally be a traffic control signal at the top of the grade, coordinated with the signal or signals below so that a vehicle permitted to enter the descending grade will be able to proceed at the indicated speed without stopping on or at the foot of the grade. This plan greatly reduces the hazard from vehicles unable to stop on slippery hills.

These exceptional cases should be decided on the basis of a thorough analysis of facts—never on the basis of petitions or complaints alone.

A combination of the above warrants may be used to develop a formula satisfactory not only for determining the feasibility of installing signals at one location but also for arriving at a priority so that a proper sequence for the installation of a number of signals may be determined. Such a formula is also helpful in identifying locations where traffic signal operation is no longer necessary.

Section 214.—Selection of Type of Fixed-Time Control Mechanism

Where any of the previously described warrants is satisfied and the decision has been made to install a fixed-time signal, it is necessary to select the type of fixed-time control mechanism to be used. The possible choices include the following, the advantages and limitations of which are set forth in sections 215 to 218:

1. Non-synchronous fixed-time controller for isolated intersections.
2. Program type of fixed-time controller for isolated intersections.
3. Synchronous type of fixed-time controller for isolated intersections.
4. Controllers providing for coordination.

Section 215—Nonynchronous Fixed-Time Controller for Isolated Intersections

This type of controller is the least desirable. Its operation, and hence the resultant timing, varies with changes in line voltage and temperature. Controllers of this type already purchased should be shifted to relatively unimportant isolated intersections warranting signalization where:

1. There is little likelihood that the signal installation will ever be coordinated with any other; and
2. The fixed lengths of cycle and intervals will be tolerable during all hours of traffic control (Stop-and-Go) operation.

Section 216.—Program Type of Fixed-Time Controller for Isolated Intersections

This type of controller provides for a limited number of changes in cycle length and in the proportions allotted to various Go intervals. Such controllers may be used at isolated intersections where:

1. There is little likelihood that the signal installation will be coordinated with any other;
2. There are marked variations for considerable periods in the traffic demand, as, for example, where the major traffic stream enters on different Go intervals in the morning and evening peak periods; and
3. With this program in effect, delays are not unreasonable.

Section 217.—Synchronous Type of Fixed-Time Controller for Isolated Intersections

This type of controller involves the use of a synchronous motor and should be used at isolated intersections where:

1. The installation is likely to be coordinated with one or more other signal installations but interconnection with a master controller is determined to be unjustified economically; and
2. The fixed length of cycle and intervals will be tolerable during all hours of traffic control operation.

This type of controller is almost always preferable at intersections for which the nonsynchronous type is suitable.

Section 218.—Controllers Providing for Coordination

Two types of control are available for coordination. One of these involves noninterconnected synchronous motors, the other a master controller interconnected to local controllers at each signal installation in the system. Sections 225 and 226 discuss the various degrees of flexibility attainable by these two types. The selection should be based upon:

1. The volumes of traffic involved;
2. Variations in traffic volume during the hours of intended Stop-and-Go control;
3. Variations between traffic volumes in the two directions on the highways involved; and
4. An analysis of the differences of cost involved.

In general, the noninterconnected synchronous motor plan 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. If funds do not immediately permit interconnection and the use of a master controller, it is possible to install synchronous motor controllers of a type which can later be utilized in a very flexible type of system. Under such conditions, the use of synchronous controllers of this type is recommended.

Section 219.—Signal Timing in Accordance With Traffic Requirements

As pointed out in the discussion of signal operations in sections 185 to 194, 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 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 principal 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.

This problem 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 a platoon 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 will be made to present a full treatment of the subject in this manual. The Traffic Engineering Handbook, published by the Institute of Traffic Engineers and the National Conservation Bureau, contains a helpful discussion of the significant details of signal timing and describes a number of practical refinements possible in traffic signal systems.

Section 220.—Division of Total Cycle Time

Reference has been made to the importance of assigning Go 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 those 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 busses 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.

To illustrate, 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 3 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 $V_t$ and $V_s$ 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, $T_t$ and $T_s$, would then be approximated as follows:

$$
T_t = \frac{V_t}{T_t} = 400
$$

$$
T_s = \frac{V_s}{T_s} = 250
$$

(1)
and \( T_a + T_s = 50 \) seconds (total Go time)

Solving for \( T_a \) in (2) and substituting in (1):

\[
T_a = 400 \quad \text{whence} \quad T_a = 31 \text{ seconds.}
\]

From (2), \( T_s = 50 - 31 = 19 \text{ seconds.} \)

In the second case, assume that the time spacing between vehicles, or departures headway, \( H_a \) and \( H_s \), is in 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:

\[
T_a = \frac{V_a \times H_a}{250} = 400 \times 3
\]

\[
T_s = \frac{V_a \times H_s}{250} = 250 \times 5
\]

Solving for \( T_a \) in (2), and substituting in (3):

\[
T_a = \frac{400 \times 3}{250} = 48 \text{ seconds.}
\]

From (2), \( T_s = 50 - 24 = 26 \text{ seconds.} \)

It should be emphasized that such 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 obtained under certain off-peak 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.

Section 221.—Coordination of Fixed-Time Signals

In general, all fixed-time signals within 1000 feet of one another and controlling the same traffic should be operated in coordination. Even at greater distances coordination may be desirable under certain conditions (see sec. 231 for required coordination with railroad grade-crossing signals).

Great inconvenience and delay result from independent, noninterrelated operation of closely adjacent signal installations operating on fixed-time 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 (see sec. 239).

Section 222.—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 fixed-time signals. These are defined as simultaneous system, alternate system, progressive system, and flexible progressive system.

Section 223.—Simultaneous System

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

In its simplest form it involves the use of one controller for a series of signals. At all intersections the timing is precisely the same and indications change simultaneously to show green at each signal facing main street traffic and red to all side streets, and similarly throughout the cycle. A basically simultaneous system may be made more efficient by utilizing independent controllers at critical intersections to permit some adjustment in interval timing in accordance with local intersection requirements.

Intersections less than 300 feet apart often constitute a serious coordination problem. At normal traffic speeds the time required to move from one intersection to the next 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 Go interval on the main 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 least with the continuous movement of traffic. Frequently this will result in virtually simultaneous operation of these two signal installations. Except for this limited application and perhaps other occasional exceptions, the use of the simultaneous system is not recommended.

In most applications the simultaneous system has serious operating disadvantages:

1. The simultaneous stopping of all traffic along the highway prevents continuous movement of vehicles and tends to result in high speed between stops, but low over-all speed.

2. Cycle length and interval proportioning are usually controlled by the requirements of one or two major intersections in the system. This often creates serious inefficiencies at the remaining intersections.

3. On streets carrying numerous streetcars, there is an extremely heavy power drain at the beginning of the Go interval.

4. When the main street is completely filled with a continuous line of traffic and this traffic is stopped on a red indication, vehicles from the side street often have difficulty in turning onto or in crossing the main street.

Section 224.—Alternate System

In the alternate system all signals change their indications at the same time, but adjacent signals or groups of signals show opposite
indications alternately along a given highway. The alternate system is
usually an improvement over the simultaneous system in that through a
series of intersections so controlled there can be favorable conditions, con-
tinuous movement of groups of vehicles at a predetermined speed, this being completely achieved only where the
lengths of the blocks, or of the alternating groups of blocks, are equal.
The inflexibility of the alternate system lies in the fact that the main
street cannot at any intersection have more than half the cycle for a
Go interval without a corresponding loss of time for the Go interval
at an adjacent intersection. Hence, for maximum efficiency of through
movement the cycle must be divided into equal Go and Stop intervals.
Under this condition the side streets all receive as much Go time as
the main street, which is ordinarily not consistent with the relative
requirements of traffic on the main and side streets.

The alternate system can be operated with a single controller, but this
arrangement is not recommended. Although the alternate system can
be used on a street where blocks are of equal length to control speed-
ing and to provide equal facility of movement in either direction
through the system, it does have limited application for the following
reasons:
1. It requires substantially equal Go intervals for both main- and side-street
traffic, which is likely to be inefficient at most of the intersections.
2. It is not well adapted to a street having blocks of unequal length.
3. If the signals are alternated by groups the capacity of the roadway is mate-
rially reduced during heavy traffic since the latter part of the vehicle group
will be stopped by the second signal in the group (assuming they are being operated in
pairs) when the signal indication changes.
4. Adjustments for changing traffic conditions are difficult to make.

Section 225.—Simple Progressive System

In the simple progressive system, a common cycle length is used at
each intersection and Go indications are given independently in accord-
ance 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.

Synchronous-motor-driven controllers operated by a common or elec-
trically synchronized source may be employed without interconnection
in the progressive system and this will serve satisfactorily until some
difficulty causes one or more of the controllers to get out of step. The
proper time relation between signal indications at the various locations
in the system must then be re-established by adjusting, with the aid of a
stop watch, the offsets of those timers which are out of step.

If a master controller is used and connected to a circuit which runs
to all signal controllers in the system, there can be a constant super-
vision of the time relation between successive signal indications, and
timers can be required to keep in step. Flashing signal operation can
be obtained at any or all intersections, either by local time switch if non-
interconnected or from the master controller if interconnected.

The simple progressive system is normally far more efficient than
either the simultaneous or the alternate system but does not provide the
full flexibility possible in a completely modern traffic signal system.

Section 226.—Flexible Progressive System

The flexible progressive system incorporates all the advantages of
the simple progressive system and has a number of additional ad-
vantages. A common cycle length is used throughout, but Go in-
tervals are scheduled independently to meet to the extent possible
the demands of traffic for movement through the system as well as
at individual intersections. Through the use of modern two- and
three-dial equipment, timing adjustments to meet efficiently the
widely varying needs of traffic at individual intersections and
throughout the system are possible. Predetermined timing pro-
grams can be set up on the multi-dial controllers to favor rush-hour
movements at appropriate periods during the day or week, midday
or off-peak traffic demands, and other conditions requiring special
timing schedules and coordination. Such refinements offer great
advantages over the unchanging timing plans of earlier progressive
signal systems. Careful measure of the demands of traffic and the
potential value of the flexibility features in the multi-dial systems
should be made before acquiring control equipment for use in flexible
progressive systems.

True flexibility is obtained by the interconnection of all controllers
in the system with a master controller to permit not only the supervi-
sory check of the coordination between signals but one or more of
the following additional features:
1. Remote control of changes in offset relation between controllers to favor
movement in one direction at certain times, such as for inbound and outbound
peaks.
2. Remote control of changes in total time cycle or in interval timing, or
both, to meet the varying requirements of traffic at various periods of the day.
3. Flashing signal operation at any or all intersections.

In general, a properly designed and operated flexible progressive
system is the fixed-time system best adapted to the efficient move-
ment of traffic. Its advantages include the following:
1. Continuous movement of entire groups of vehicles is possible with a mini-
imum of delay and at an average speed planned for the system. This advantage
can be realized on both the main and side streets.
2. A high degree of efficiency can be obtained by proportioning the intervals
to fit the traffic requirements at each intersection.
3. Speeding is discouraged because a vehicle must make frequent stops if it
exceeds the speed for which the system is planned.
4. Differences in block lengths can be handled better than with other fixed-
time systems.

Section 227.—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 street blocks (assuming signals at all intersections) especially
where reasonably high speeds are possible (this particular condition does not
affect the simultaneous system).
2. Narrow streets, where parking and loading interfere with free movement.
3. Traffic composed of units of widely differing speeds, such as streetcars,
bus, trucks, and passenger automobiles, especially on narrow streets.
4. Certain types of complicated intersections, such as those requiring three or
more Go intervals per cycle.
5. Heavy volume of vehicles turning from or into the artery, especially if the
block into which they turn is short or otherwise limited in capacity.

Nevertheless, some type of flexible progressive system generally gives
the best results possible by fixed-time control under such street and
traffic handicaps as cannot be removed or relieved.

When conditions along a given highway where it is desired to in-
stall a signal system are not particularly favorable to fixed-time flex-

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liable progressive control, consideration should be given to the possibilities offered by progressive traffic-actuated control or independent traffic-actuated control (see sec. 230).

Section 228.—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 apt to develop. This often destroys coordination at these intersections and through the system, with disadvantages generally more important than the possible improvement achieved by portioning 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.

Section 229.—Speeds for Progressive Systems

The 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. Except in business districts, progressive systems along arteries are generally timed for speeds ranging from 20 to 30 miles per hour. In general, the more heavily used the roadway, the narrower the road, the more built-up and busy the district, the shorter the blocks controlled, the more mixed the types of traffic, or the more pedestrians and cross-street traffic there are, the slower should be the design speeds.

Local authorities should be careful to avoid design speeds that will conflict with State laws governing speeds.

Section 230.—Signs Indicating Timed Speed

Traffic Signal Speed signs (sec. 38) should be erected to guide drivers operating under an alternate, simple progressive, or flexible progressive system. Where the system timing is different for various periods of the day, however, the resulting speeds may vary enough to make this posting of speed signs impractical. When such signs are used, they should be mounted on, or as near as possible to, each signal where the timed speed changes, and at intervals of not more than two blocks throughout the system.

Section 231.—Coordination With Railroad Crossing Signals

Traffic signals near railroad crossings shall be interconnected with the flashing light or wig-wag signals or gates at the railroad grade crossing and with all other traffic signals on the same street or intersecting street within 500 to 1,000 feet of the crossing, to the extent necessary to prevent conflicts between rail and highway traffic. The signals shall be so operated as to prohibit, to the maximum extent practicable, vehicles from entering the roadway between the railroad crossing and the intersection near the crossing as trains approach and travel through the crossing area.

On the approach of a train, all signals which could permit vehicles to reach the crossing area without having another red indication before them shall, unless already showing red, go immediately to yellow and then to red, remaining red until the crossing is clear. At other times, these signals should operate as standard flashing signals or as Stop-and-Go signals, depending on the conditions warranting their installation.

Section 232.—Rate of Flashing

When fixed-time signals are put on flashing operation, the rate of flashing shall be not less than 50 nor more than 60 times per minute. The illuminated period of each flash shall be approximately equal to the nonilluminated period.

Detailed information on flashing signals will be found in sections 278–283. In every case, the change to flashing operation should be made during or immediately following the main-street green interval.

E—TRAFFIC-ACTUATED SIGNALS

Section 233.—Definition

A traffic-actuated signal is a type of traffic control signal in which the intervals are varied in accordance with the demands of traffic as registered by the actuation of detectors or push buttons.

1. A semi-traffic-actuated signal is a type of signal in which means are provided for traffic actuation on only some of the approaches to the intersection.

2. A full traffic-actuated signal is a type of signal in which means are provided for traffic actuation on all of the approaches to the intersection.

3. A speed control signal is a type of signal in which means are provided for traffic actuation on some or all approaches and which provides Go indications in such a manner that vehicle speeds on one street are limited to a preselected maximum value.

Section 234.—Warrants for Intersection Control

Because traffic-actuated signals at intersections do not normally delay traffic except when it needs to be delayed to avoid conflict with traffic on cross streets, it is not advisable to set values of minimum traffic volumes or other fixed warrants for their installation. There are, however, a number of factors that should be considered and weighed before selecting and installing such signals. These factors are:

1. Vehicular volumes.—At intersections where the volume of vehicular traffic is not great enough to justify fixed-time signalization, traffic-actuated signals may be applied if other conditions are such as to indicate the need for Stop-and-Go signal control and if the cost of the installation can be justified by the conditions.

2. Cross traffic.—When the volume of traffic on a main street is so great as to restrict and jeopardize unduly the movement of vehicular traffic on a minor street, semi-traffic-actuated signals may be installed to provide an assignment of right-of-way to the cross street without seriously delaying traffic on the main street. Traffic-actuated signals are desirable at all such signalized intersections except in cases when they constitute a part of a coordinated or progressive system, thus warranting fixed-time control.

3. Peak-hour volumes.—When signal control is required at an intersection during only a 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.
4. Pedestrians.—If the principal need for a traffic signal is to accommodate pedestrian traffic, traffic-actuated signals are usually desirable and may be economically justified. Most urban intersections with heavy pedestrian volumes also have heavy vehicular volumes and vice versa, and thereby warrant traffic signals. However, signals may be warranted at special locations, such as in the vicinity of schools, when pedestrian crossings are the primary consideration. In these special cases, traffic-actuated signals will delay vehicular movements only when these movements are in use by pedestrians.

5. Accident hazard.—When a study of intersection conditions indicates that signalized control would be an effective remedy for the accident hazard existing, but the warrant for establishing full-time signals is not met, a traffic-actuated signal installation may be justified.

6. Wide traffic fluctuations between streets.—When the preponderance in traffic variables from one street to another, at an intersection where one or more of the warrants for fixed-time signals is substantially fulfilled, full traffic-actuated control will usually provide the greatest efficiency in intersection operation.

7. Complicated intersections.—Traffic-actuated signals offer special advantages at complicated intersections with conditions substantially warranting signals, where multiple traffic phases are needed, in that they are capable of skipping phases when some of the streets are not being used. In each case, they use only the time actually required, thus providing a high degree of efficiency.

8. Unwarranted signals.—When traffic authorities are compelled to install traffic signals at locations where they are not needed for safe and efficient movement, traffic-actuated types should be employed. They cause a minimum of unnecessary delay and thus do not tend to break down public respect for traffic signal control.

9. Progressive signal systems.—When the spacing or character of some intersections in a fixed-time progressive signal system is such that satisfactory progressive timing cannot be achieved, traffic-actuated control may be employed at those intersections.

10. Speed control.—If approach speeds present a particular hazard at intersections, in addition to normal intersection problems, full-actuated control employing speed control on the artery may be installed for best results.

Section 235.—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:

1. Speed control.—Traffic-actuated signals may be used to control speeds at the approaches to special roadway locations, such as bridges, sharp curves, and entrances to towns. They may be of especial value at school zones if speeds average higher than 25 miles per hour in rural or 22 miles per hour in urban areas.

2. One-way restricted zones.—At locations on two-way roadways where traffic can only move in one direction at a time, such as at narrow bridges and tunnels, traffic-actuated signals may be applied to assign the right-of-way and to provide clearance intervals in accordance with traffic requirements.

3. Midblock pedestrian protection.—Pedestrian crossings concentrated at schools where intersections are a considerable distance apart, and at other midblock points, often justify use of pedestrian-actuated signals.

The installation of signals between intersections for the purposes indicated above should be accompanied by the erection of appropriate signs advising the motorist 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.

Section 236.—Types of Traffic-Actuated Control, and Factors Governing Selection

As indicated earlier, traffic-actuated signal controls may be classified in two general categories: (1) Semi-traffic-actuated, and (2) full traffic-actuated. There are also several special types of applications for traffic-actuated equipment. These include: (1) coordinated control, (2) pedestrian-actuated control, (3) speed control, and (4) one-way restricted zone control. All these special applications make it essential that a thorough knowledge of the traffic and physical facts be obtained prior to selecting equipment for installation.

To aid those who have the problem of choosing the proper type of equipment for a particular job, the characteristics of the two general types of traffic-actuated control and the several special applications are presented below.

Section 237.—Semi-Traffic-Actuated Control

Semi-traffic-actuated control is applicable primarily to intersections of a heavy artery with high-speed traffic artery with a relatively lightly traveled minor street. Detectors are located only on the minor street. The signal is normally green on the artery, changing to the minor street only as a result of vehicle or pedestrian actuation. In some instances the minor street green interval is of fixed duration, but 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 may not be retained on the minor street even when traffic demand thereon is heavy. Upon the expiration of the required, or maximum, minor street interval, the Go signal will revert automatically to the artery 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 at once to minor street actuation.

Section 238.—Full Traffic-Actuated Control

Since semi- or part traffic-actuated control does not measure the demands of certain traffic streams, it cannot attain the efficiency of full traffic actuation. Therefore, full traffic-actuated control should be selected for intersections where failure to take into account certain traffic demands will seriously affect the efficiency of control. In full traffic-actuated control, detectors are installed on all approaches to the intersection and right-of-way is assigned to a street only as a result of actuation thereon. Where there is no traffic on either street, the green indication will ordinarily remain upon the street to which it was last assigned. The duration of the green interval on any street is dependent upon the traffic demand on that street, subject to a maximum time limit in the event of a continued demand and the presence of traffic on the other street. In the event of continued actuation, transfer of right-of-way will be made to waiting cross traffic after a predetermined maximum period, and in this case, right-of-way will automatically be returned to the first street at the earliest opportunity without the necessity of further actuation.

Full-traffic-actuated control 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 for 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.

A recently developed form of full traffic-actuated controller operates upon a "volume-density" basis, many of its circuits being subject to
automatic and continuous adjustment with respect to variations in volume, relative densities on the two opposing traffic phases, elapsed time between actuation and assignment of right-of-way, and other factors. As this form of control is essentially "platoon responsive," it is capable of facilitating progressive platoon movements. This is discussed in the following section on coordinated control.

Section 239.—Coordinated Control

There are three principal applications of traffic-actuated equipment in coordinated operation of a series of related signalized intersections. These are characterized by the features described in the following paragraphs:

Supervisory background cycle.—In one type, a supervisory background cycle is imposed upon a series of semi-traffic-actuated controls, this being accomplished by a master timer sending out impulses over interconnecting wires to each semi-actuated controller, thereby local synchronizing each controller at each intersection. The background cycle is set up in the same manner as for fixed-time control, a time-space chart being worked out for the series of intersections that will give the maximum travel band through the area. The function of the supervisory cycle is to assure that the local semi-actuated controllers provide at least the minimum of Go time, and in the time relation called for in the time-space chart. In addition to this minimum Go time, each semi-actuated controller adds to its Go 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 Go interval may seriously overload a subsequent intersection at which cross-traffic requirements are greater.

It is also apparent that the above type of operation does not provide the speed control characteristics of a fixed-time progress system, and hence should be used only where the consideration of moving maximum amounts of traffic with the least delay outweighs the desirability of speed limitations.

Volume-density control.—Another form of coordinated traffic-actuated control is accomplished by the use of full-actuated controllers of the so-called volume-density type. This type of control operates so that no background cycle or pre-actuated element is used. The controller is capable of responding to the natural platoon movement of traffic. The impulses from an advancing group of cars are received by the controller and tend to produce a forcing effect in keeping a Go interval for the group of vehicles, this tendency being increased by a carry-over effect impressed upon the control mechanism by the passage of the previous platoon. Increased spacing of vehicles at the end of the platoon is sensed by the controller and utilized to terminate the movement. It is thus possible for platoon movements to affect a series of traffic-actuated intersections of this type in such a way as to set up a pattern of progressive movement based on natural speeds and spacings.

Section 240.—Pedestrian-Actuated Control

Operation of both the semi- and full traffic-actuated controls, as well as certain types of fixed-time controls, can be accomplished by pedestrian push buttons. Such actuation may affect movements in any of the following ways:

1. Pedestrian actuations are handled on the same basis as vehicle actuations. No special signal indications are shown for pedestrians.
2. Vehicle indications (WALK, WAIT, or equivalent) are shown in parallel with the vehicle indications. The most desirable types of such controls provide for a termination of the Walk indication sufficiently in advance of the expiration of the vehicle interval to permit persons who have left the curb to complete the crossing of the street without vehicular interference.
3. An exclusive pedestrian interval, normally justified only under conditions of low vehicle volume at high speeds and heavy pedestrian movement, is inserted in the signal cycle and during this interval all vehicle traffic is stopped.
4. In the case of pedestrian-actuated signals that normally operate in conjunction with fixed-time intersection signals and which have the pedestrian interval introduced into the cycle upon actuation of the push button, the pedestrian interval can either be taken from one of the vehicular traffic green-light periods or be added to the cycle without decreasing either of the green periods. During flashing operation of signals at right-of-way (secs. 167, 270), actuation of the push button causes the flashing signals to give a steady red Stop indication to the major traffic flow crossed by pedestrians, with or without a special Walk signal.

Equipment is also available for the protection of pedestrian cross walks at midblock locations, schools, and similar locations. With this form of control the green signal shows normally to traffic on the thoroughfare, right-of-way being accorded to the cross walk upon push-button actuation. After providing an interval for pedestrian movement, these signals automatically return the right-of-way to vehicular traffic, and give a predetermined and adjustable minimum interval to this traffic before the pedestrian indication can again be obtained.

Section 241.—Speed Control

Speed control can be applied at nonintersection locations and also at full traffic-actuated controlled intersections.

An application of speed control.—An adaptation of the traffic-actuation principle affords a means of controlling the speeds of vehicles at nonintersection locations such as curves, bridges, and school zones. The component parts of the system are a speed controller, a vehicle detector, and a traffic signal. The signal indication is normally red or Stop. The detector actuation at a point in advance of the signal initiates the timing of a delay interval after which the signal is changed to a green or Go indication in time to permit the passage of a vehicle traveling at or below the maximum allowable speed (i.e., covering the distance between detector and signal in not less than the timed interval). A vehicle traveling at too great a speed will arrive at the Stop line before the signal changes from Stop to Go and hence will be required to stop. Successive vehicles, if closely enough spaced, will extend the Go indication, but when the maximum spacing is exceeded the red indication is at once shown and speed control again becomes effective.

This type of control should always be identified with appropriate signs so that the motorist will recognize and understand the function of the signal. For the same reason, some additional enforcement may also be desirable for a period immediately after the installation is made.

Intersection speed control.—At intersection locations where speeds on the artery approach present a particular hazard in addition to the normal problems of intersection control, it may be desirable to employ full traffic-actuated control incorporating speed-control features on the artery.

All signals normally show red in the absence of approaching traffic. A single vehicle approaching the intersection on the main street and crossing the detector will receive the green indication at the end of a vehicle approach period. If the vehicle is traveling at or below the speed designated as safe for the location, the green indication will
come on in time to allow passage through the intersection without delay. If, on the other hand, the approaching vehicle is coming too fast, it will have to slow down or stop before the green indication will be displayed.

A car following close enough so that it crosses the detector before the green indication period for the first car expires will extend the green period, thus allowing itself time to pass the intersection. A platoon of cars can all proceed through the intersection, by this extension feature, without interruption. The speed control inherent in this latter case lies in the fact that the first car of the platoon is monitored for speed as it approaches the intersection. Should a break occur in the line of cars long enough so that the speed of the next car will not be so controlled the signal will have returned to red. This car upon crossing the detector will institute a new vehicle approach period and thus monitor its own speed.

The vehicles approaching the signal on the main street from one direction and obtaining the green indication do not cause the same indication to be displayed toward the other direction on the main street. Signals facing in the opposite direction on the main street remain red in order to have a speed-monitoring effect on traffic which may approach from that direction.

When the signal is not to transfer the right-of-way to the cross street, the main-street indication changes directly from green to red in order to give immediate speed-monitoring effect for other approaching vehicles. This is a satisfactory procedure inasmuch as had the next following car been close enough to get into trouble it would have been close enough to extend the green light period.

If cross traffic is waiting and traffic is moving through the intersection in one direction on the main street, a driver approaching the signal from the other direction on the main street will not receive a green indication unless there is time for him to go through the intersection before right-of-way is transferred to the cross street. If there is not sufficient time before the right-of-way transfer is made, the green light will be returned to the waiting driver on the main street after the cross-street traffic has passed. On the cross street the display of the red signal is always preceded by a yellow signal as in normal signal operation.

A clearance interval is always provided for the main street when the green signal is to be given to the cross street. If there are cars on the main street between the detector and the intersection that must be stopped a yellow signal is displayed to them during this period. Otherwise the clearance period is all red.

A maximum period limits the time that moving traffic on either street can maintain its right-of-way against waiting cross traffic.

Section 242.—One-Way Restricted Zone Control

Full traffic-actuated control equipment is available for use at a narrow passage, such as a bridge or tunnel, which is not wide enough to allow traffic to flow in opposite directions simultaneously. This control operates essentially as a full traffic-actuated 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.

Section 243.—Detectors and Controllers

Since the traffic-actuated signal, as its name implies, responds to vehicle or pedestrian actuations by providing Go indications for the appropriate movements, it is necessary that detector and controller equipment be designed for this service. In this respect, traffic-actuated signals differ considerably from fixed-time signals, which require no detector units and a somewhat simpler timing mechanism for their control. The design characteristics of the various types of detectors and controllers that have been developed for use with traffic-actuated equipment are described below.

Section 244.—Types of Detectors

A wide variety of detectors can be used with traffic-actuated signals. These are classified as follows:

1. Pressure-sensitive detectors.
2. Magnetic detectors.
4. Light-sensitive detectors.
5. Pedestrian push-button detectors.

Some of these offer special advantages for particular physical and traffic conditions, and the type of detector should therefore be selected with care. To aid in this selection, the characteristics of the several types are outlined below.

Section 245.—Pressure-Sensitive Detectors

Pressure-sensitive vehicle detectors are of two general types. The most common type is actuated when crossed by vehicles traveling in any direction. In the other type, used principally on narrow two-way roadways, actuation occurs only when the detector is contacted by vehicles traveling in one direction. A brief explanation of the two types follows:

Non-directional detectors.—Detectors of the non-directional type operate on the open-circuit principle, with electrical contact established only at the moment that vehicle wheels pass over the rubber surface.

Directional detectors.—With directional type detectors, vehicle impulses are passed into the signal controller from traffic in one direction only, impulses being rejected from traffic moving in the opposite direction. While similar in appearance to non-directional detectors, the directional type contains two separate sets of electrical contacts, rather than one.

Section 246.—Magnetic Detectors

Magnetic detectors are available in two general types: (1) non-compensated, which have a wide zone of influence; and (2) compensated, which have a sharply defined zone of influence. They are not rendered inoperative or continuously operative by parked cars or by other fixed metal objects within their zone of influence.

Non-compensated detectors.—Non-compensated magnetic detectors are mounted in or under the roadway surface and are usually capable of providing a road coverage up to about 15 feet on either side of the detector. They are not recommended for use at locations subject
to severe and fluctuating electromagnetic influences such as are caused by streetcars and trolley busses.

Compensated Detectors.—Detectors of the compensated magnetic type involve two magnetic circuits and are so designed that their operation is not affected by extraneous electromagnetic influences. They are characterized by a relatively sharp definition of their zone of influence, usually extending only about 6 inches beyond each end of the detector. A further characteristic of the best detectors of this type is that they are capable of a high degree of directional discrimination and can, therefore, be used to detect vehicles by lanes of travel.

Section 247.—Sound-Sensitive Detectors

Detectors of this type consist of a hollow metal chamber with a steel top plate and are actuated by sound waves set up in the chamber by the passage of a vehicle wheel over the top plate. These detectors are not affected by ordinary external noises not associated with the passage of wheels over their surface. They are not directional.

Section 248.—Light-Sensitive Detectors

The passage of a vehicle can be detected by the interruption of a beam, or beams, of light between a light source and a photoelectric cell or cells. Sequential interruption of two beams of light can be utilized to provide directional detection.

Section 249.—Pedestrian Push-Button Detectors

In addition to detectors for registering the demand of vehicles approaching an intersection, it is in many instances desirable 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.

Section 250.—Types of Controllers

Because traffic conditions are subject to wide variation, it is necessary that traffic-actuated controllers have sufficient flexibility of operation to meet all normal conditions and as many others as possible. Ready adjustments of various time intervals over wide ranges should be possible.

In traffic-actuated controls, Go signal intervals for the approaches with actuation have an initial portion, to permit standing traffic to get into motion, which is followed by one or more unit extensions, the number and duration of which are determined by the traffic itself, within the timing limitations pre-set on the controller. A maximum period protects waiting cross traffic against undue delay in the event that traffic on the other street is very heavy. Clearance intervals are provided at the end of the Go interval.

In semi-traffic-actuated control, the Go interval is normally accorded to the main street, being called to the cross street upon actuation by cross-street traffic. The cross street has an initial portion, which may be followed by an extension portion if cross-street traffic requires. The main street, not having actuation, has only one predetermined period, namely, the minimum period. At the end of this minimum period the Go indication can again be transferred to the cross street in response to actuation. The main-street minimum period should therefore be set at a value to take care of the expected normal main-street traffic.

All these portions, intervals, and periods should be readily adjustable by suitable knobs, pins, or dials which will require the use of no tools. The limits between which they should be adjustable for the various types of control are presented below in sections 251 to 255.

The ranges of timing adjustment shown are desirable, but in actual operation the adjustment of Go intervals within the range provided should be made with a view toward safeguarding pedestrian movements, as well as to facilitate vehicle traffic.

Section 251.—Two-Movement, Semi-Traffic-Actuated Controller with Time Extension

For this type of control the interval timing should be adjustable within the following limits:

<table>
<thead>
<tr>
<th>Time</th>
<th>Seconds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum period</td>
<td>10–90</td>
</tr>
<tr>
<td>Clearance</td>
<td>2–10</td>
</tr>
<tr>
<td>Cross-street initial portion</td>
<td>2–12</td>
</tr>
<tr>
<td>Cross-street extension limit</td>
<td>2–12</td>
</tr>
<tr>
<td>Cross-street maximum period</td>
<td>10–90</td>
</tr>
</tbody>
</table>

Section 252.—Two or More Movements, Full or Semi-Traffic-Actuated Controller with Time Extension

The various intervals in two-, three-, or four-phase controls, in phases susceptible to extension by traffic actuation, should be adjustable between the following limits:

<table>
<thead>
<tr>
<th>Time</th>
<th>Seconds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum period</td>
<td>10–60</td>
</tr>
<tr>
<td>Initial period</td>
<td>2–30</td>
</tr>
<tr>
<td>Extension limit</td>
<td>2–10</td>
</tr>
<tr>
<td>Clearance</td>
<td>1–10</td>
</tr>
</tbody>
</table>

Phase no: having extension by traffic actuation should have minimum green signal intervals adjustable between 10 and 90 seconds on the main streets and between 10 and 60 seconds on minor streets.

Section 253.—Traffic-Actuated Speed Control for Nonintersection Locations

Nonintersection speed controls such as may be used on a curve or at a school zone, narrow underpass, or other roadway hazard should have intervals adjustable between the following limits:

<table>
<thead>
<tr>
<th>Time</th>
<th>Seconds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle approach period</td>
<td>0–10</td>
</tr>
<tr>
<td>Extension limit</td>
<td>0–10</td>
</tr>
<tr>
<td>Vehicle indicator period</td>
<td>3–30</td>
</tr>
</tbody>
</table>

Section 254.—Two-Movement, Full or Semi-Traffic-Actuated Controller With Speed Control

This is the type of controller used at intersections of two streets where excessive speed on one of the streets is an important factor. The various intervals should be adjustable between the following limits:

<table>
<thead>
<tr>
<th>Time</th>
<th>Seconds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum period</td>
<td>10–90</td>
</tr>
<tr>
<td>Initial portion</td>
<td>2–30</td>
</tr>
<tr>
<td>All extension limits</td>
<td>1–10</td>
</tr>
<tr>
<td>All clearance intervals</td>
<td>1–10</td>
</tr>
<tr>
<td>All vehicle approach periods</td>
<td>1–10</td>
</tr>
</tbody>
</table>
Section 255.—Two-Movement, Full Traffic-Actuated Controller
With Automatic Adjustments of Periods With Respect to
Traffic Volume, Relative Density, and Elapsed Time

In this type of control the various intervals and actuations should
be adjustable between the following limits:

| Minimum initial portion... seconds | 5-60 |
| Increase of initial portion per car... do | 0-1-2 |
| Number of cars before minimum initial portion starts to increase cars... 5-60 |
| Passage period... seconds | 5-15 |
| Maximum time within which extension limit can be reduced... do | 10-90 |
| Waiting time to reduce extension limit to minimum... do | 10-90 |
| Number of waiting cars to reduce extension limit to minimum cars... 5-40 |
| Density of traffic into green signal (number of cars per 10 seconds to reduce extension limit to minimum)... cars... 5-40 |
| Clearance Interval... seconds | 1-10 |
| Maximum period... do | 10-90 |
| Carry-over effect... percent | 10-90 |

Section 256.—Two-Phase, Full Traffic-Actuated Control for One-
Way Restricted Zone

With this control the initial portions, extensions, and usual yellow
clearance intervals, as well as the maximum intervals, should be timed
in accordance with the usual procedure given heretofore. In addition,
the all-red clearance interval, during which traffic that has entered
the restricted area during the display of the Go signal is allowed to
clear, should be adjustable between the limits of 10 and 70 seconds.

Section 257.—Additional Flexibility for Controllers Used in Co-
ordinated Systems

Where a series of intersections along a main street equipped with
traffic-actuated control, using actuation on the cross streets only, are
to be coordinated, the equipment may be such that the time at which
each control can respond to a cross-street actuation is determined by
a master timer, or by a local synchronous motor timer.

Section 258.—Provision for Manual Operation

Manual operation of traffic-actuated signals is not generally
recommended. The wide flexibility of operation they afford is usually
adequate to care for varying traffic demands. However, where traffic
conditions are so variable as to make manual operation of the
controller desirable, switches for manual operation of the controller may be provided. Such switches should not be
accessible to police officers who are not especially trained and experienced
in the direction and control of traffic at intersections.

When the control is being operated manually, actuation of the
manual control push button causes the signals to show actuations of
the signals that are normally displayed in the next period. The display
will then remain unchanged until the manual control push button is
again actuated.

Section 259.—Installation of Traffic-Actuated Signals

The installation of signal heads, controllers, and certain other ele-
ments of traffic-actuated signals involves the same considerations as
those described in sections 175-187, applicable to all signals. Details
of the location and installation of vehicle detectors, however, deserve
special explanation because of their importance to the efficient and
reliable operation of traffic-actuated signal equipment.

Section 260.—Distance of Vehicle Detectors From Stop Line

The proper location for vehicle detectors in relation to the Stop line
depends upon the type and operating characteristics of the controller,
the speed of vehicles approaching the intersection, physical charac-
teristics of the roadway (grades, widths, parking, visibility, etc.), and
special signal functions (turns on separate intervals, stoppage in-
road traffic before entrance to high-speed artery, etc.). With conven-
tional full and semi-traffic-actuated controller equipment used under
average conditions—i.e., level roadway, not more than two traffic lanes
in each direction, and good visibility—good results have been obtained
when the distance from the Stop line to the detector is related to the
speed of approaching vehicles as follows:

<table>
<thead>
<tr>
<th>Distance from stop line (feet)</th>
<th>Speed (miles per hour)</th>
</tr>
</thead>
<tbody>
<tr>
<td>110</td>
<td>Less than 20</td>
</tr>
<tr>
<td>140</td>
<td>20-30</td>
</tr>
<tr>
<td>170</td>
<td>30-40</td>
</tr>
<tr>
<td>210</td>
<td>40-50</td>
</tr>
<tr>
<td>225</td>
<td>Over 50</td>
</tr>
</tbody>
</table>

When the approach to the intersection is on a grade, the distance from
the Stop line should be increased about 4 percent for each 1-percent
down grade and decreased about 4 percent for each 1-percent up grade.
Where there are more than two lanes approaching the intersection,
and visibility is not restricted, it has often been found desirable to increase
the above distances by small amounts, since higher speeds through the
intersections usually can be allowed with safety. The increased
distances in such cases may be as much as 15 percent greater than the aver-
age values given above. Under no condition should detectors be loc-
ated less than 40 feet from the Stop line. Where they are installed
to permit left-turn movements on a separate signal interval, detectors
are usually placed much closer to the intersection than for the control
of normal traffic. Where a minor road intersects a high-speed route, it
may be desirable to force most cars on the side road to stop before enter-
ing or crossing the artery. In such cases, the spacing of detectors
should be shortened on the side street so that most cars will arrive at
the Stop line on a red signal.

Bus stops, filling-station drives, and other special conditions near an
intersection may necessitate the installation of a second detector very
near the Stop line. Such installations would in no way interfere with
the spacing of the initial detectors of the street so affected.

Speed-control signals normally require longer spacings between de-
tectors and Stop lines, so that desired speed reductions can be achieved
gradually and stops required only in cases of abnormally high speeds,
or at intersections when right-of-way has been assigned to the cross
street. For normal roadway and traffic conditions, when speed-control
features are provided, the recommended distance from the Stop line

* Eighty-five percent of vehicles approaching the intersection at or below given speed at
approximate point of detector location.
to the detector as related to the speed of approaching vehicles\textsuperscript{11} is as follows:

\begin{tabular}{|c|c|}
\hline
Speed (miles per hour) & Distance from
\textsuperscript{\textit{stop line}} (feet) \\
\hline
20-30 & 190 \\
30-40 & 220 \\
40-50 & 205 \\
50-60 & 225 \\
Over 60 & 350 \\
\hline
\end{tabular}

These values should also be increased or decreased, as explained previously, to accord with roadway grades, visibility, and special traffic conditions. Where speed control is applied at an intersection, the above values should be used in locating detectors on the artery and those previously given for standard traffic-actuated control should be used in locating the detectors on the side road. Detectors for use with two-movement, full traffic-actuated controllers with automatic adjustment of periods with respect to traffic volume, relative density, and elapsed time should be located farther from the stop line than would be the case with other types of traffic-actuated control. This enables the control to recognize the presence of platoons of cars and in general to get the complete data on traffic conditions necessary to regulate its refinements of control. For normal roadway and traffic conditions, the recommended distance from the stop line to the detector as related to the speed of approaching vehicles\textsuperscript{11} is as follows:

\begin{tabular}{|c|c|}
\hline
Speed (miles per hour) & Distance from
\textsuperscript{\textit{stop line}} (feet) \\
\hline
20-30 & 240 \\
30-40 & 270 \\
40-50 & 320 \\
Over 50 & 375 \\
\hline
\end{tabular}

For special roadway conditions, these values may be changed as recommended for other types of installations discussed above. Where the greatest coordination effect is desired between a series of intersections, the detector spacings on the street on which through movement is desired should be increased about 20 percent.

Section 261.—Location of Vehicle Detectors From Center Line

Pressure-sensitive and sound-sensitive detectors should be placed transversely in the roadway so that all vehicles approaching the intersection cross them with one or more wheels. No vehicle moving away from the intersection should normally cross the detector. When physical conditions are such that more than an occasional car leaving the intersection crosses the detector, a directional detector should be installed so that this traffic will not actuate the controller unnecessarily.

The end of the pressure-sensitive detector nearest the center line of the road should usually be placed about 3 feet therefrom. If the approach side of the road requires more than one detector to cover it satisfactorily, the detectors should be spaced so that the end of the rubber surface of one will be 4 feet from the next. This will ensure that no car can pass between the detectors without causing an actuation.

\textsuperscript{11} See footnote 10, page 151.

In the case of pressure-sensitive detectors, consideration must be given to parked vehicles. In areas where curb parking is allowed, detectors should never be located so that a properly parked car can stand with a wheel on the detector. On one-way streets, the entire roadway should be given detector coverage, except as spaces may be necessary from each curb for parking.

The compensated type of magnetic detector should be buried in the road with the end nearest the center line approximately 4 feet therefrom. If additional compensated magnetic detectors are required to cover the distance to the curb, they should be spaced so that their ends will be about 4 feet apart. The compensated magnetic detector has a rather sharp cut-off and, in general, a vehicle must pass either over it or within 6 inches of its end to cause an actuation.

The uncompensated type of magnetic detector does not have as sharp a cut-off as the compensated type. Its zone of influence is not as clearly defined. It should, therefore, be located under the path traveled by the right wheels of a car traveling in the center of the lane to be covered. An uncompensated magnetic detector can usually be adjusted to cover about 25 feet of roadway. In special cases uncompensated magnetic detectors may be located in or on the shoulder of the roadway.

Light-sensitive detectors, employing photoselectric cells and light beams across the roadway, are normally used only at special locations such as bridges and tunnels. They must be mounted so as to detect the approach of vehicles by having the light beam interrupted by the passing cars. The beam may be in either a vertical or horizontal plane, but if mounted in the open, consideration must be given to snow and ice conditions if the beam is used in a vertical plane. Parked cars would seriously handicap their use in many places.

Section 262.—Installation of Pedestrian Detectors

Pedestrian detectors or push buttons are available for mounting on either wood or steel poles. They should be conveniently located near each end of crosswalks used by pedestrians at the roadway location controlled by the signal. The detector should be 3\(\frac{1}{2}\) to 4 feet above the sidewalk and in view of persons using the crosswalks. Pedestrian-type detectors should be mounted just above the detectors, explaining their purpose and use (sec. 59).

When pedestrian detectors are provided for special purposes, such as at school crossings, and are to be used only by authorized persons, lock switches should be installed so that the detectors can be operated only by persons with keys. Such detectors are not intended for the use of the general public and the supplemental signs are not necessary.

Section 263.—Installation of Streetcar Detectors

When streetcars operate on streets where traffic-actuated signal equipment is installed, it is necessary to provide special devices to detect the approach of the streetcars. The distance of detectors from the stop line is usually determined in the same manner as that for vehicle detectors. However, when streetcar stops or other conditions make it necessary, the spacing between the streetcar detectors and the stop line may be shortened, or a second detector may be provided on each approach to the signal.
Section 264.—Operation and Adjustment of Traffic-Actuated Signals
As with all types of signals, it is necessary that appropriate equipment be installed to meet the normal traffic requirements of a given roadway or location. Assuming the availability of the proper equipment, it is necessary to adjust and operate the equipment as nearly in accordance with the needs of vehicular and pedestrian traffic as is possible.

Section 265.—Continuous Operation
Traffic-actuated signals of all types should be operated at all times as Stop-and-Go devices except:
1. As a caution signal (flashing yellow) when interconnected with other signals and/or remotely controlled for emergency vehicles such as fire trucks; or
2. As a caution signal, or as a combination caution and Stop signal (flashing yellow on certain approaches and flashing red on others) when failure of controller, wiring, or signal lamps prevents normal operation.

Since traffic-actuated signals, properly timed, cause a minimum of unnecessary delays, there is no justification for changing them to flashing operation during light traffic periods. Right-of-way is normally denied approaching motorists only when intersecting streets are in use by others or when safe approach speeds are exceeded.

Section 266.—Time Intervals and Adjustments
In order to obtain the greatest efficiency from traffic-actuated equipment, the correct setting for the various time intervals must be determined. This often requires the installation of a test circuit after the installation has been made. The following explanation is intended as a guide for those not thoroughly acquainted with the general principles and terminology associated with the operation of traffic-actuated equipment. It is suggested that reference also be made to the glossary of signal terms on page 205.

In general, it will be desirable for a person not familiar with such time intervals and adjustments to secure the advice of an experienced representative of the company that manufactures the equipment or of some other well-informed person, until the desired settings and adjustments are well understood. It should be added that these settings and adjustments sound more complicated than they are found to be with experience.

The minimum Go signal interval on a street having traffic-actuated control with time extension includes an initial portion followed by a unit extension. If there is a line of cars crossing the detector after the initial portion has expired, each car crossing the detector will cancel the unexpired remainder of the previous unit extension and initiate a new unit extension. Thus ten cars successively extending the Go period will not necessarily cause the Go signal to remain on that street for ten times as long as one car would. The Go signal will be transferred to the cross street, if there is waiting traffic thereon, following the expiration of the last unit extension.

From the foregoing explanation it can be seen that the unit extension represents the time spacing between cars approaching the intersection in excess of the minimum required to clear traffic. The time spacing is transferred to the cross street, if there is waiting traffic thereon, following the expiration of the last unit extension.

Since traffic-actuated equipment controls permit considerable flexibility in the selection of the Go period, extreme care must be used to safeguard pedestrian movements by provision of a minimum length of Go interval which will accommodate the slower pedestrians.

The various settings and adjustments necessary for operation of traffic-actuated controls are as follows:

Initial portion.—The initial portion should be adjusted to a time which, added to a unit extension, will permit a solid line of cars between the detector and the Stop line, clear the intersection.

Maximum period.—The unit extension should be set so that a car which has actuated the detector, if it is traveling at a speed normal for the street, will clear the intersection before leaving the right-of-way. 

Minimum period.—The maximum period is brought into play only when continuous traffic prevails and cross traffic waits. The point to be considered in setting it is that, when traffic becomes very heavy on the street, the signal operates, in effect, as a fixed-time signal, and the maximum period determines the proportion of time to be allotted to each street.

Clearance interval.—The clearance interval is set at a value that will permit moving traffic to come safely to a halt when a Stop signal is displayed.

Vehicle approach interval (speed control of the nonintersection type).—This interval should be set at such a value that a car moving at the normal speed will receive the Go signal in time to permit continuing at that rate of speed. Cars approaching at a greater speed will be forced to reduce their speed before proceeding.

Vehicle approach interval and unit extension (speed control with intersection control).—The vehicle approach interval and the unit extension should be set in accordance with the suggestions previously given for adjustment of the maximum period. Cross-traffic periods (not speed monitoring) should be adjusted as in any traffic-actuated control with time extension.

Interval adjustments for volume-density controllers.—The minimum initial portion should be set at a value that will permit a few cars to pass through the intersection before its expiration. A larger number of vehicles will need more time than the minimum initial portion and since the detectors are far enough away from the intersection so that a large number of vehicles can be between the detector and the intersection, provision must be made for lengthening the initial portion. The number of cars that can pass the detector before the expiration of the minimum initial portion starts to increase should be the number that can move into the intersection during the minimum initial portion. Each car should be given additional time to be added to the minimum initial portion. The amount of time added by each car is called "increase of initial portion per car" and should be set at such a value that, under heavy traffic conditions, waiting cars will clear the intersection before the expiration of the minimum initial portion plus the increase thereof. Streetcar and bus actuations are sometimes weighted so as to affect the controller in the same manner as would several passenger automobiles. The passage time should be set at a value that will permit a car crossing the detector on the green indication to clear the intersection before the expiration of that time. This is the case when the vehicle is moving at a reasonable speed. This can be set long, because if traffic conditions are such that this long period should not be granted, a shorter period determined by requirements of traffic will automatically be substituted thereafter.

In this type of control the timing is responsive to several traffic conditions, including the following:
1. Number of cars waiting on cross street.
2. Time that cross traffic has been waiting.
3. Time spacing of vehicles on street with Go signal.
4. Number of cars waiting at the red indication increases, the duration of the unit extension on the street having the Go signal is simultaneously decreased, thus requiring denser traffic in order to hold the Go signal thereon. As the number of cars waiting at the red light increases, the extension for that street is reduced until the low limit set on the controller is reached. The time to which the extendible portion can be reduced, as well as the number of cars waiting against the red light required to cause such reduction, can be adjusted independently for each street. Thus the controller constantly balances the number of cars waiting on the Stop signal against the density of the traffic moving into the Go signal, and allocates the right-of-way. A plate of cars waiting on the detector on the main street can reduce the extendible portion of the Go interval on the cross street so markedly that it will secure preferential treatment and pass through the intersection without delay. The controller also keeps track of the time spacing between cars approaching the Go signal and if cross traffic is waiting gives the Go signal to the other street when some preselected amount of straggling occurs. If the pattern of approach-
ing traffic gives an average spacing between cars of 1 second, the unit extension time on that street is automatically set slightly in excess of 1 second. When the main body of the platoon of cars has passed and cars begin to approach at intervals considerably greater than 1 second (in other words, to stream), the right-of-way will be transferred to the cross street. If traffic is waiting there, if the average time spacing of cars approaching the Go signal is 2 or 3 seconds, the control will automatically set the unit extension at slightly greater than 2 or 3 seconds, again operating to transfer the right-of-way when queuing occurs if there is waiting cross traffic. This effect is adjustable on two dials. One of these sets the minimum time to which the extension limit can be reduced by the rate of traffic flow, and the other sets the rate of traffic flow which will reduce the extension period to the set low level. Until the low level is reached, the more frequent the approaching traffic on the Go signal, the shorter the extendible portion for that indication will become.

The features described above work together to recognize both the approach and clearance of a platoon of vehicles and to operate the signals so as to facilitate these movements.

Intervals for one-way restricted zone controls.—The timing of the initial portion, the unit extension, and yellow clearance interval is the same for a one-way restricted zone signal control as in any traffic-actuated signal having extendible portions. The all-red clearance interval should be set at a value that will permit a car which has crossed the detector to clear the restricted area before the Go signal is given in the opposite direction.

Section 267.—Interval Sequence

Traffic-actuated intersection controllers should provide time intervals for any desired combination of signal indications. The sequence of intervals for each traffic phase should be fixed so that the various intervals will always appear in order when the signal indications on that phase are changed.

Equipment for standard traffic-actuated control (speed control excluded) at intersections should provide any of the standard color sequences. Sequences are limited by the number of intervals available in the controller and the wiring of the controller to the signal heads, so that they may be fixed except as they may be changed by rewiring or, of course, by the replacement of the controller.

Interval sequence for traffic-actuated speed control signals can be varied for the application. Typical sequences provide for a normal red indication which changes to green, yellow, or flashing yellow after termination of a vehicle approach period. After the expiration of an expansion period, or periods, the signal indication automatically returns to red.

Speed control with traffic actuation at a two-movement intersection causes the signal to operate as a modified three-phase signal. Two of the phases correspond to the two approaches of the speed-controlled street and these may, of course, operate in unison. The third phase handles the cross street.

Controllers actuated by pedestrian detectors may provide distinct pedestrian intervals, with WALK and WAIT indications, as a part of the signal sequence, or they may simply provide a green indication for the street being used by the pedestrian in the same manner as would actuation by an automobile of a vehicle detector on that street.

Section 268.—Rotation of Phases

The rotation of intervals with traffic actuation is determined by 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.

With three- or four-phase operation, intervals for each phase will be initiated only when the demand exists, and the duration of intervals is governed by traffic demand. If there is no demand for one of the phases, that phase is omitted in the rotation of phases.

F—SPECIAL PEDESTRIAN SIGNALS

Section 269.—Definition

Special pedestrian signals are highway traffic signals erected for the exclusive purpose of directing the pedestrian to take some specific action.

Section 270.—Warrants

Special pedestrian signals should be installed in conjunction with traffic signals already meeting one or more of the minimum warrants previously set forth in the sections on fixed-time or traffic-actuated signals (secs. 207-213, 234, 235), under the following conditions:

1. When pedestrians and vehicles move during the same phase and the pedestrian volume crossing the major street averages at least 500 persons per hour for any 5 hours of an average day; or
2. When a separate phase is provided for pedestrian movement in all directions (as at a T intersection or traffic circle), all vehicles being stopped; or
3. When heavy vehicular turning movements require an extra pedestrian indication for the protection and convenience of the pedestrian desiring to cross the street; or
4. When pedestrian movement on one side of an intersection is permissible while through vehicular traffic is stopped to protect a turning movement on the other side of the intersection; or
5. When a separate phase is made available for pedestrians in the operating cycle of a traffic-actuated signal; or
6. When a traffic signal is installed solely for the benefit of pedestrians, as at a factory entrance or a school crossing, even though the volume in warrant No. 2 above, is not equal or exceeded.

Special pedestrian signals should not ordinarily be installed at school crossings where schoolboy patrols can be used effectively or where students can be directed to cross at locations already controlled by signals or police officers. However, they may be warranted at an intersection used as a school crossing under the following condition:

When minimum vehicular volume entering an urban intersection from all directions averages 400 or more vehicles per hour for the opening and closing hours of school, and minimum pedestrian volume crossing the urban major street averages 100 or more persons per hour during the opening and closing periods of the school. The rural warrant is 50 percent of the foregoing urban volumes.

Other conditions, any one of which may warrant special pedestrian signals at a midblock school crossing, are as follows:

1. When intersections adjacent to the school are more than 1,000 feet apart; or
2. When two lanes or more of traffic in an urban area are moving at average speeds of 35 m. p. h. or greater, during the opening and closing periods of school, and students are required to cross these lanes; or
3. When two lanes or more of traffic in a rural area are moving at average speeds of 35 m. p. h. or greater, during the opening and closing periods of school, and concentrations of students are required to cross these lanes; or
4. When a sharp vertical or horizontal curve or a view obstruction, or a combination of these, exists adjacent to the school crossing, and creates a serious hazard.
In connection with signals installed for school crossings, it should be understood that the signal is not the only remedy nor is it necessarily the best solution to the perplexing problem of traffic conflicts between vehicles and school children. Brief periods during which the hazards are unusually high may often be better handled by officer control. In some circumstances, the pupils' respect for traffic signal indications may be so low as to make the installation of a signal a contributory factor in increasing rather than decreasing accidents. The obedience response to officer control is usually less uncertain. Complete facts should be obtained and studied by competent traffic engineering authorities before decisions are made on special school signal installations.

Section 271.—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 signals at midblock locations adjacent to schools is to be avoided. However, when such signals are required by some unusual condition, the traffic-actuated type of control should be employed.

Section 272.—General Design Requirements
Special pedestrian signals should meet with three important conditions:

1. They should be located directly in the line of vision of each crossing of pedestrians in either direction.
2. The 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 to 150 feet.
3. The signal indications must be such that they will not be mistaken as vehicle indications by motorists.

The two types of design described below for pedestrian control signals are approved as standard:

1. Two sections of the standard traffic signal face, one lens of which contains the word WALK, the other lens of which contains the word WAIT. (See fig. 25 for details of the WALK lens developed by the Institute of Traffic Engineers. The design of a typical WAIT lens having a dark orange glass is also shown in figure 25. There is no generally accepted pattern for this lens as yet.)
2. A rectangular box-type signal in which the words WALK and DON'T WALK are displayed in red neon lights.

A WALK signal shall always be accompanied by a WAIT or DON'T WALK indication. Particular care should be given to the design and construction of the neon type of pedestrian signal so that in case of an electrical or mechanical failure of the word WALK, the word WALK will also remain dark.

Lenses should carry letters at least 3 inches high, so designed and spaced as to give a maximum of legibility. Figure 26 shows a WALK and WAIT installation that has proved to be effective. In order to avoid possible confusion to vehicle drivers, letters should appear illuminated on a black background.

Special pedestrian signals are not as yet in extensive use and experimentation with their design details, subject to the conditions stated above, is desirable.

Section 273.—Meaning of Indications
Indications in special pedestrian signals should have the meanings ascribed to them in this section and no other meaning. These meanings are in accord with those set forth in Act V of the Uniform Vehicle Code (sec. 35).

Figure 25.—(ABOVE) WALK lens design: Institute of Traffic Engineers. (BELOW) A typical WAIT lens design.

WALK.—While the WALK lens or indication is illuminated, pedestrians facing such 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.

WAIT or DON'T WALK.—While the WAIT or DON'T WALK lens or indication is illuminated, no pedestrian shall start to cross the roadway in the direction of such signal, but any pedestrian who has partially completed his crossing on the WALK signal shall proceed to a sidewalk or safety island, if one is provided, while the WAIT or DON'T WALK signal is showing.
Section 274—Location

Special pedestrian signals should be mounted on corner posts with the bottom of the signal not lower 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 each crossing of pedestrians in any direction. These signals may be mounted separately or with the traffic control signals.

Signals installed at midblock school crossings shall follow the usual location standards except that post-mounted signals shall be located 15 feet in advance of the marked cross walk and on the right-hand side of the street. A stop line shall also be provided.

Section 275—Operation

Most of the general requirements relating to the operation of highway traffic signals apply to the operation of special pedestrian signals as well. It may sometimes be that the need for a separate pedestrian phase will diminish considerably before vehicular volumes drop to a point where flashing operation would be employed. In such cases, it may be desirable to add the time normally allotted to the pedestrian phase to the main-street green interval during this interim period.

Section 276—Phases and Intervals

The length in seconds of phases and intervals provided for special pedestrian signals is normally determined by those allotted to vehicular traffic in the operation of fixed-time or vehicle-actuated traffic signals. When the average walking time required for the pedestrian to cross the roadway is greater than the time necessary for vehicular traffic to clear, however, the former should govern the length of the pedestrian WALK interval, and the vehicular interval should be adjusted accordingly. Since the pedestrian, as well as the vehicle, requires a clearance interval, the period during which it is not possible to start and complete a crossing at the normal walking speed should always be recognized by an appropriate signal indication. Such indication should be given the pedestrian sufficiently in advance of the transfer of vehicle right-of-way to prevent pedestrians from being stranded in the middle of the street.

G—OTHER SPECIAL TRAFFIC SIGNALS

Section 277—Types of Special Traffic Signals

Special traffic signals include:
1. Flashing beacons and signals.
2. Lane-direction traffic signals.
3. Traffic signals at drawbridges.

Flashing Beacons and Signals

Section 278—Definition and Application

Flashing beacon.—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 rapid intermittent flashes.

Flashing signal.—A flashing signal is a standard highway traffic signal in which the yellow or red lens in each face is illuminated by rapid intermittent flashes.

Flashing beacons and signals perform a very useful function at locations where traffic or physical conditions do not justify a conventional type of Stop-and-Go installation. At other special points of hazard, experience has indicated that the flashing beacon or signal is the only device sufficiently conspicuous to identify the hazard to the motorist.

Section 279—Warrants

The warrants presented herein for flashing beacons and flashing signals differ from the latter are merely a utilization of an existing traffic signal installation.

Flashing yellow beacon.—The installation of a flashing yellow beacon may be warranted as an advance warning device at 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. Proximity of a fire station.
4. sudden change from rural conditions, where relatively high speeds are safe, to those of an urban district where speed must be reduced.

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. Instead of or in conjunction with Stop and Advisory Speed signs 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 proceeding with caution on the other.

This type of installation is especially effective at intersections where approach speeds are in excess of that warranted by conditions, and drivers are not adequately impressed with the need for stopping or reducing speed by the use of standard or approximate Stop signs, by Stop signs and Advance Warning signs, or by Advisory Speed signs.

2. Minimum vehicular volume entering an urban intersection from all directions averages 300 vehicles per hour for at least 2 consecutive hours, of which vehicular traffic entering the intersection from the minor street or streets averages at least 30 vehicles per hour for the same hours. Warrants for rural areas are 50 percent of the above urban volumes.

10 The effect of flashing yellow in reducing traffic speed, according to available evidence, has not been particularly potent; and care should be taken not to overestimate the value of the flashing yellow indication. The idea is sound, however, and better public understanding and enforcement may eventually prove its worth.
3. Two or more reported accidents in a 12-month period of types susceptible of correction by cautioning and stopping of traffic.
4. Intersection on or at the bottom of a long or steep grade where excessive speed may prevail.

**Flashing red and yellow signal.**—A combination flashing yellow (Caution) and flashing red (Stop) signal is warranted as part of a signal installation not continuously operated on a Stop-and-Go basis if the volume of traffic falls below the minimums given in sections 208 to 210.

When signals normally operated as Stop-and-Go signals are put on flashing operation in accordance with the above, 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 the street is the same as the safe approach speed on the other street or streets, the street having the lower speed should be given the flashing yellow (Caution) indication and other approaches should be given a flashing red (Stop) indication.
3. If the safe approach speed on any street in urban areas is below 8 miles per hour, that street, regardless of other considerations, should be given the flashing red (Stop) indication. The corresponding safe approach speed value for rural areas is 12 miles per hour. Other approaches should be given the flashing yellow (Caution) indication.

**Section 280.—Types of Control**

Types of control used with flashing signals or beacons are as follows:

1. The motor flashing switch, usually installed in the housing of the flashing beacon, is used solely to provide intermittent illumination of the beacon lenses.
2. Where flashing operation of the conventional fixed-time or traffic-actuated signal is desired, the control is provided by an electrical mechanism supplementary to the timer. This operates in a manner similar to the motor flashing switch to provide intermittent illumination of the signal lenses.

**Section 281.—Design**

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

1. Each signal unit lens shall have a visible diameter of 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 from 10 to 200 feet under all atmospheric conditions, except dense fog, both day and night.
3. The color of the lens shall be red for Stop and yellow for Caution.

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

**Section 282.—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 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, they should not be more than 14 1/4 feet nor less than 14 1/2 feet above the pavement. 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.

**Section 283.—Operation**

The illuminating element in a flashing yellow (Caution) or flashing red (Stop) beacon or 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 approximately equal to the nonilluminated period.

Flashing beacons should generally be operated continuously throughout the 24-hour period.

Flashing signals also should generally be operated continuously throughout the 24-hour period, except when conditions warrant their being changed to standard Stop-and-Go operation. In every case, the change from Stop-and-Go to flashing operation should be made during or immediately following the main-street green interval.

**Lane-Direction Traffic Signals**

**Section 284.—Definition and Application**

Lane-direction or off-center traffic signals are traffic signals used to control the direction of traffic movement by individual lanes of a street or highway. These installations are distinguished by signal units over each lane of the roadway, and supplementary signs are often used to explain their significance.

**Section 285.—Warrants**

Lane-direction traffic signals may be warranted when:

1. Vehicular traffic flow in one direction on a two-way street, highway, bridge, or tunnel, having three lanes or more, exceeds the reasonable capacity of the lane or lanes normally used for traffic moving in that direction and, at the same time, traffic flow from the opposite direction does not require the number of lanes which it is generally allocated.
2. Traffic movement at toll booths and single-lane tunnels requires reversal in direction of traffic flow for efficient operation.
3. Traffic movement in one direction at an entrance or exit of a parking lot at an industrial plant, stadium, or similar location greatly exceeds the capacity of the traffic lanes allocated for handling balanced traffic flow.
4. Heavy traffic flow 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 of two lanes for uphill and one lane for downhill movement.
5. 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.

**Section 286.—Types of Control**

The type of control provided for lane-direction signals should be such as to permit automatic or manual operation of the signals. The control mechanism should permit the illumination of the red lenses 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 signal so that it can be illuminated only when the red signal shows in the opposite direction. Normally, no more than a two-lens signal, having red and green lenses, is required for each direction of traffic, since the signals are not often placed at intersections.
Section 287.—Design
Traffic signal heads used for controlling the direction of movement by lanes shall have two faces. Each face controlling a lane subject to reversing traffic flow shall contain standard red and green lenses and otherwise shall follow the general design specifications of traffic control signals. In lanes not subject to reversing traffic flow signal faces shall have a single lens, red or green, whichever is appropriate for the location. Mountings shall permit the signals to be suspended over lanes on cables or fixed supports.

Section 288.—Location
A traffic signal head with a face for each direction of traffic to be controlled shall be located over the center of each lane of the roadway at the beginning and end of the lane-controlled section. If the area to be controlled is more than 1,000 feet in length, or if the vertical or horizontal alignment is curved, intermediate signal heads shall be placed over each lane at frequent enough intervals so that motorists will at all times be able to see at least two signals along the roadway and have a definite indication of the lanes specifically reserved for their use. At the terminal and intermediate signal installation points on the lane-controlled section, signal heads above the various lanes shall be located in a transverse straight line at right angles with the roadway alignment.

Section 289.—Operation
All traffic signals used to control traffic movement by lanes shall be coordinated and wired to a master control which will operate so as to permit all two-lens signal 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 shall also 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 light traffic periods or during an emergency traffic situation.

The system shall operate either manually or automatically through the use of a time clock.

Traffic Signals at Drawbridges

Section 290.—Application
Signals installed at drawbridges to control vehicular traffic are a special application of highway traffic signals.

Section 291.—Warrants
Traffic signals should always be used in conjunction with gates and the other types of protection commonly employed at drawbridges.

Section 292.—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.

Section 293.—Location
Traffic signals shall be located at both ends of the movable span. To assure positive visibility, two signal heads should be mounted on each approach to the movable span, one on the right and the other on the left side of the roadway. They should ordinarily be not less than 50 feet nor more than 100 feet from the end of the movable span.

Section 294.—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 gate is closed and the draw is open, the signals shall show a continuous red indication. After the gate is closed and the gates 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.

H—TRAIN-APPROACH SIGNALS AND GATES

Section 295.—Railroad Grade-Crossing Protection
Signals are inadequate protection at railroad crossings where highway traffic is heavy, train movements are frequent, or visibility is seriously obstructed. At such crossings there should be installed train-approach signals to indicate the approach and passage of trains, or gates which will extend into or across the roadway to prevent vehicles from entering upon the crossing while trains are approaching and occupying the crossing. The following sections deal only with signals and gates of the automatic type.

Train-Approach Signals

Section 296.—Classification and Definitions
Train-approach signals are classified as flashing-light or wig-wag signals.
A flashing-light signal is an electrically or mechanically operated signal in which indication of the approach of a train is given by two horizontal red lights flashing alternately at predetermined intervals, producing the equivalent of a signal given by a watchman swinging a red lantern.
A wig-wag signal is similar to the flashing-light signal except that
the indication of the approach of a train is given by a swinging disk and a red light enclosed in the disk.

Section 297.—Warrants

Train-approach signals shall be installed at railroad-highway grade crossings to warn highway traffic of any approaching train where the volume of traffic of both the railroad and the highway warrants, or where physical obstructions to clear vision exist on highway approaches. Such signals shall be used for no other purpose.

Section 298.—Types of Control

Flashing-light and wigwag signals may be controlled manually, or automatically through track circuits arranged so that the flashing-light signals will operate until the rear of the train reaches or clears the crossing and so that the signals will operate upon the approach of trains from either direction on the tracks for which protection is provided.

Section 299.—Design

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

1. Signal lights shall shine in both directions along the highway and be mounted horizontally. The distance between centers of lights shall be 30 inches. Lamps shall preferably be not less than 7 feet nor more than 9 feet above the surface of the highway.
2. Lenses or roundels shall be a minimum of 8 3/4 inches in diameter, and shall be in accordance with Signal Section Specification 69 of the Association of American Railroads.
3. The Railroad Crossbuck sign (sec. 89) 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 the center of 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 a minimum of 5 inches in diameter, and shall be in accordance with Signal Section Specification 69 of the Association of American Railroads.
4. The Railroad Crossbuck sign (sec. 89) and the signal shall be mounted on the same post.

Section 300.—Location

Whichever type is used, one signal shall be placed on each side of the track.

The location of signals 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 pavement, angle of crossing, and visibility to drivers approaching the crossing.

Section 301.—Installation

Flashing-light and wigwag signals shall be installed in accordance with the standards as prescribed in Railroad Highway Grade Crossing Protection, Bulletin No. 3 (or subsequent issue), Association of American Railroads, Joint Committee on Grade Crossing Protection.

Section 302.—Operation

Automatic signal devices used to indicate the approach of trains shall so indicate for not less than 20 seconds before the arrival of the fastest train operated over the crossing.

Local conditions may require a longer operating time, but too long an operation by such trains is undesirable. Uniform time control for all trains 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.

Lights in the flashing-light type of signal shall flash alternately. The number of flashes of each light per minute shall be 30 minimum, 45 maximum. Lights shall each burn the same length of time. Total burning time of both lamps shall be practically the entire operating time.

Each flashing-light unit shall provide an indication having a beam candlepower of uniform intensity at any angle up to 10 degrees on either side of the axis, and the range at any point in the 20-degree angle under bright sunlight conditions, with the sun at or near the zenith, shall not be less than 1,500 feet when a 10-watt lamp rated at 1,000 hours is burned at rated voltage.

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, 45 maximum.

The signal light 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 30 degrees when a 10-watt lamp rated at 1,000 hours is burned at rated voltage.

Section 303.—Maintenance

Signals shall be kept well painted and in a good state of efficiency. The surfaces of lenses on signal lamps shall be kept free from such deposits as soot or other materials, since these will seriously affect their efficiency.

Railroad—Highway Grade-Crossing Automatic Gates

Section 304.—Application

Automatic gates, where installed, shall be provided as an adjunct to the Association of American Railroads' recommended automatic crossing signals of the flashing-light or wigwag type described above. When indicating the approach of a train they shall present toward the highway in both directions the appearance of a horizontal arm carrying three red lights and extending over the traveled roadway a sufficient distance to cover the lane or lanes used by traffic approaching the crossing.

Section 305.—Warrants

Automatic gates and signals of the type described herein shall be installed at railroad—highway grade crossings to warn highway traffic of any approaching train where the volume of traffic of both the railroad and the highway warrants, or where physical obstructions to clear vision exist on highway approaches. These devices shall be used for no other purpose.
Section 306.—Types of Control

Automatic gates may be controlled manually, or automatically through track circuits. The gates 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, and they shall operate upon the approach of trains from either direction on the tracks for which protection is provided.

Section 307.—Design

The gate arms and housings containing the arm-operating mechanisms shall be mounted on the post supporting the crossing signals and Railroad Crossbuck sign.

The bottom of the gate arms, when in the horizontal or lowered position, shall be not less than 3 feet nor more than 4 feet above the crown of the roadway and, when not indicating the approach of a train, shall neither obstruct nor interfere with highway traffic.

The mechanisms shall be so designed that if the arms, while being raised or lowered, strike or foul an object, they will readily stop and, on removal of the obstruction, shall assume the position corresponding with the control apparatus.

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.

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

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

Section 308.—Location

The location of automatic crossing gates for railroad-highway grade-crossing protection shall be determined after inspection and study at the site. In addition to providing for adequate clearances, consideration shall be given to the type of pavement, angle of crossing, and view when approaching the crossing.

Section 309.—Installation

Automatic gates shall be installed in accordance with the standards prescribed in Railroad Highway Grade Crossing Protection, Bulletin No. 3 (or subsequent issue), Association of American Railroads, Joint Committee on Grade Crossing Protection.

Section 310.—Operation

Circuits for the operation of automatic gates shall be so arranged that the gates will start to assume the horizontal position between 3 and 5 seconds after the warning signals start to operate. Gates shall reach a 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.

Uniform time control for all train speeds is the most desirable arrangement, and at crossings where there is a 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 in the operation of automatic gates should be considered.

Section 311.—Maintenance

Automatic gates shall be kept well painted and in a good state of efficiency. The surfaces of lenses on signal lights on the gate arms shall be kept free from such deposits as soot or other materials, since these will seriously affect their efficiency.