Chapter Twelve
TRAFFIC SIGNAL DESIGN

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Chapter Twelve
TRAFFIC SIGNAL DESIGN

12.1 GENERAL

The design of traffic signals is one of the most dynamic fields of traffic engineering. Although this chapter will address several traffic signal design issues, it is impractical to present a complete traffic signal design guide. For detailed design information, the reader should review the latest editions of the references in Section 12.1.3. The intent of this chapter is to provide the user with an overview of the traffic signal design issues and to present MDT's applicable positions, policies and procedures.

12.1.1 MUTCD Context

Throughout the MUTCD, the words "Standard," "Guidance" and "Option" are used to indicate the appropriate application of traffic control devices. Section 2.3 in Part I of the MDT Traffic Engineering Manual defines the Department's application of these qualifying words.

12.1.2 Adherence to Design Criteria

Chapter Twelve presents the design criteria for the application of traffic signals on individual projects. In general, the designer is responsible for making every reasonable effort to meet these criteria. However, recognizing that this will not always be practical, the following sections discuss the Department's procedures for identifying, justifying and processing exceptions to the governing traffic signal design criteria.

12.1.2.1 Design Exceptions

The designer must seek an internal MDT design exception when the proposed traffic signal design criteria does not meet the following:

1. "Standard" conditions in the MUTCD,
2. "Guidance" conditions in the MUTCD,
3. MDT Detailed Drawings, and
4. MDT Policies from the Chief Engineer or Director.

12.1.2.2 Documentation

The type and detail of documentation needed to justify a design exception will vary on a case-by-case basis. The following is a list of potential items that may need to be documented for a specific design exception:

1. crash data;
2. environmental impacts;
3. right-of-way impacts;
4. construction costs; and
5. serviceability impacts (e.g., traffic level-of-service).

12.1.2.3 Procedure

The following procedure will be used to process an identified design exception:

1. Project Engineer. The Project Engineer will assemble the documentation for the design exception request. See Section 8.8 of the MDT Road Design Manual. This documentation will be submitted to the Traffic Engineer.

2. Traffic and Safety Engineer. The Traffic and Safety Engineer will review the design exception and, if in agreement, will sign the request.

12.1.3 References

The following is a list of recommended publications for the selection, design, construction and installation of traffic signals in Montana:

1. Manual of Uniform Traffic Control Devices, FHWA, ATSSA, AASHTO and ITE;

2. Highway Capacity Manual, Transportation Research Board;

3. Standard Specifications for Road and Bridge Construction, MDT;

4. MDT Detailed Drawings, MDT;

5. Electrical detailed drawings, MDT;

6. Chapter Six “Roadside Safety,” MDT Traffic Engineering Manual, MDT;

7. Chapter Fourteen “Roadside Safety,” MDT Road Design Manual, MDT;

8. Traffic Detector Handbook, FHWA;

9. Traffic Control Systems, National Electrical Manufacturers Association;

10. Standard Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals, AASHTO;

11. Traffic Engineering Handbook, Institute of Transportation Engineers;

12. Manual of Transportation Engineering Studies, Institute of Transportation Engineers;

13. Manual of Traffic Signal Design, Institute of Transportation Engineers;

14. Preemption of Traffic Signals at or Near Active Warning Railroad Grade Crossings, Institute of Transportation Engineers;

15. Traffic Signal Installation and Maintenance Manual, Institute of Transportation Engineers;

16. Determining Vehicle Signal Change and Clearance Intervals, Institute of Transportation Engineers;

17. Official Wire and Cable Specifications, International Municipal Signal Association; and

18. National, State and local electrical codes and manufacturers' literature.

12.1.4 Project/Plan Development

The following list provides information for a traffic signal project and plan development:

1. Project Development. Chapter Eight presents a network that describes the project development sequence for a typical traffic signal project and associated responsibilities for traffic signal designer.

2. Project Coordination. During the development of a traffic signal project, the designer must coordinate with many units internal and external to the Electrical Unit. Chapter Nine discusses specific coordination responsibilities between the designer and other units and applies both to a project for which the Electrical Unit is serving as the lead unit and to a project for which the Electrical Unit is

providing project support when another unit is project lead (e.g., the Road Design Section).

3. Plan Development. Chapter Ten presents the Department's criteria for developing a set of plans applicable to traffic signal projects. Chapter Ten contains information on scale sizes, CADD requirements, plan sheet requirements, quantities, etc.

12.1.5 Definitions

The following is a list of definitions for commonly used terms in traffic signal design:

1. Accessible Pedestrian Signal. A device that communicates information about pedestrian timing in non-visual format (e.g., audible tones, verbal messages, vibrating surfaces).

2. Active Railroad Grade Crossing Warning System. The flashing signals, with or without warning gates, together with the necessary control equipment used to inform road users of the approach or presence of trains at railroad-highway grade crossings.

3. Actuated (Operation). Operation of a controller in which some or all signal phases are operated on the basis of detection.

4. Actuation. Initiation of a possible change in traffic signal phase through detection.

5. Approach. All lanes of traffic moving toward an intersection or a mid-block location from one direction, including any adjacent parking lane(s).

6. Average Day. A day representing traffic volumes normally and repeatedly found at a location, typically a weekday when volumes are influenced by employment or a weekend day when volumes are influenced by entertainment or recreation.

7. Background Cycle. The period of time provided to serve all the assigned intervals to their maximum allotted time within the coordination plan. In coordinated systems, the background cycle is common to all intersections in the system.

8. Backplate. A thin strip of material that extends outward from and parallel to a signal face on all sides of a signal housing to provide a background for improved visibility of the signal indication.

9. Cabinet. A weatherproof enclosure for housing the controller and associated equipment.

10. Call. The input into a controller as a result of the actuation of a vehicle or pedestrian detector.

11. Conflict Monitor (Malfunction Management Unit). A device used to detect and respond to improper or conflicting signal indications and improper operating voltages in a controller.

12. Controller. A complete electrical device responsible for controlling the operation of a traffic signal.

13. Coordination. The establishment of timed relationships between the interval sequences of adjacent signal installations.

14. Crosswalk. (1) The part of a roadway at an intersection included within the connections of the lateral lines of the sidewalks on opposite sides of the highway measured from the curbs or in the absence of curbs, from the edges of the traversable roadway, and in the absence of a sidewalk on one side of the roadway, the part of a roadway included within the extension of the lateral lines of the sidewalk at right angles to the centerline. (2) Any portion of a roadway at an intersection or elsewhere distinctly indicated as a pedestrian crossing by lines on the surface, which may be supplemented by a contrasting pavement texture, style or color.

15. Cycle. The period of time used to display a complete sequence of signal indications.

16. Delay. (1) A measure of the time that has elapsed between the stimulus and the response; (2) Traffic Delay. The time lost by vehicle(s) due to traffic friction or control devices (e.g., lane changes, parking maneuvers, driveways).

17. Demand. The need for service; for example, the number of vehicles desiring to use a given segment of roadway during a specified unit of time.

18. Detection. The process used to identify the presence or passage of a vehicle at a specific point or to identify the presence of one or more vehicles in a specific area. Detection also refers to the process used to identify the presence of pedestrians.

19. Detector. A device used for indicating the presence or passage of vehicles or pedestrians (e.g., inductive loop, microloop detector, pedestrian push button).

20. Dilemma Zone. A range of distances from the intersection where drivers may react unpredictably to a yellow change interval (i.e., deciding to stop or to continue through the intersection).

21. Dual-Arrow Signal Section. A type of signal section designed to include both a yellow arrow and a green arrow.

22. Extension Time. The amount of time the green interval is displayed once vehicular demand has left the inductive loop.

23. Flasher. A device used to turn signal indications on and off repetitively.

24. Flashing (Flashing Mode). A mode of operation in which a traffic signal indication is turned on and off repetitively.

25. Flashing Beacon. A single signal indication that operates in a flashing mode.

26. Full-Actuated Operation. The operation of a traffic signal in which all signal phases function on the basis of detection.

27. Interconnected. Traffic signals, signs and/or computers that are connected through common communication.

28. Interval. A discrete part of a signal cycle during which signal indications do not change.

29. Interval Sequence. The order of appearance of signal indications during successive intervals of a signal cycle.

30. Interval Timing. The passage of time that occurs during an interval.

31. Lag. An additional interval or phase that must follow the previous phase.

32. Lane-Use Control Signal. An overhead signal displaying indications to permit or prohibit the use of specific lanes of a roadway or to indicate the impending prohibition of such use.

33. Lead. An additional interval or phase that must precede the next phase.

34. Loop Detector. A device capable of sensing a change in the inductance caused by the passage or presence of a vehicle over an inductive loop embedded in the roadway.

35. Louver. A device that can be placed inside a signal visor to restrict visibility of a signal indication from the side or to limit the visibility of the signal indication to a certain lane or number of lanes.

36. Major Roadway. The roadway normally carrying the higher volume of vehicular traffic.

37. Minor Roadway. The roadway normally carrying the lower volume of vehicular traffic.

38. Offset. The time difference, in seconds, between the start of the green interval at one intersection as related to the start of the green interval at another intersection. May also be expressed in percent of cycle length.

39. Overlap. An assigned traffic movement that runs during one or more traffic phases.

40. Network. A geographical arrangement of intersecting roadways.

41. Passage Time. The amount of time the green interval is displayed once vehicular demand has left the inductive loop.

42. Pedestrian Change Interval. An interval during which the flashing UPRAISED HAND (symbolizing DON'T WALK) symbol indication is displayed. When a verbal message is provided at an accessible pedestrian signal, the verbal message is "wait."

43. Pedestrian Signal Indication. A signal head that is installed to direct pedestrian traffic at a signal installation.

44. Pedestrian Clearance Time. The time provided for a pedestrian crossing in a crosswalk, after leaving the curb or shoulder, to travel to the far side of the traveled way or to a median.

45. Permitted Mode. A mode of traffic signal control in which left or right turns may be made when a circular green indication is displayed after yielding to oncoming traffic and/or pedestrians.

46. Platoon. A group of vehicles or pedestrians traveling together as a group either voluntarily or involuntarily because of traffic signals, geometrics or other factors.

47. Point Detection. The detection of a vehicle as it passes a point along a roadway.

48. Preemption Control. The transfer of normal operation of traffic signals to a special control mode. Normal signal operation is interrupted and/or altered in deference to a special situation (e.g., the passage of a train, bridge opening, the granting of right-of-way to an emergency vehicle).

49. Presence Detection. The ability of a detector to sense that a vehicle, whether moving or stopped, has appeared in its detection area.

50. Pretimed Operation. A type of controller operation during which the length of various intervals remains constant.

51. Priority Control. A means by which the assignment of right-of-way is obtained or modified.

52. Protected Mode. A mode of traffic signal control in which there are no vehicular or pedestrian conflict movements.

53. Ramp Control Signal (Ramp Meter). A traffic signal installed to control the flow of traffic onto freeways at entrance ramps and freeway-to-freeway connections.

54. Recall. A mode of operation where a call is registered in the controller independent of demand.

55. Red Clearance Interval. An optional interval during which all directions are shown a red signal indication that follows a yellow change interval and precedes the next conflicting green interval.

56. Resistance Gate (Barrier Gate). A type of traffic gate designed to provide a physical barrier to vehicular and/or pedestrian traffic when placed in the appropriate position.

57. Right-of-Way (Assignment). Permitting vehicles and/or pedestrians to proceed in a lawful manner in preference to other vehicles or pedestrians by the display of signal indications.

58. Semi-Actuated Operation. A type of controller operation in which at least one, but not all, signal phases function on the basis of actuation.

59. Separate Left-Turn Signal Face. A signal face for controlling a left-turn movement that sometimes displays a different color of circular signal indication than the adjacent through signal faces display.

60. Shared Left-Turn Signal Face. A signal face, for controlling both a left-turn movement and the adjacent through movement, that always displays the same color of circular signal indication that the adjacent through signal face or faces display.

61. Signal Face. The front of a signal head.

62. Signal Head. An assembly of one or more signal faces together with the associated signal housings.

63. Signal Indication. The illumination of a signal lens or equivalent device or a combination of several lenses or equivalent devices at the same time.

64. Signal Installation. The traffic signal equipment, signal heads and their supports, and associated electrical circuitry at a particular location.

65. Signal Lens. That part of the signal section that projects the light coming directly from the light source and its reflector, if any.

66. Signal Phase. The part of the cycle length allotted to any vehicular or pedestrian movement.

67. Signal Section. The assembly of a signal housing, lens, and light source with necessary components and supporting hardware to be used for providing one signal indication.

68. Signal System. Two or more traffic signal installations operating in coordination.

69. Signal Visor. That part of a signal section that directs the signal indication specifically to approaching traffic and reduces the effect of direct external light entering the lens.

70. Steady (Steady Mode). The continuous illumination of a signal indication for the duration of an interval, phase or consecutive phases. The steady mode is used when a signalized location is operated in a stop-and-go manner.

71. Traffic Signal. A power-operated traffic control device by which traffic is alternately assigned the right-of-way to the various movements at an intersection or other roadway location.

72. Visibility-Limited Signal Indication. A type of signal face, signal section or signal indication designed to restrict the visibility of a signal indication from the side, or

to limit the visibility of a signal indication to a certain lane or number of lanes or to a certain distance from the stop line.

73. Warning Gate. A type of traffic gate designed to warn, but not primarily to block, vehicular and/or pedestrian traffic when placed in the appropriate position.

74. Warrant. A threshold condition that, if found to be satisfied as part of an engineering study, will result in analysis of other traffic conditions or factors to determine whether a traffic signal or other improvement is justified.

75. Yellow Change Interval. The first interval following the green right-of-way interval in which the signal indication for that interval is yellow.

76. Yield Point. The point at which the controller permits a signal phase to be terminated to service a conflicting signal phase.

12.2 PRELIMINARY DESIGN CONSIDERATIONS

An engineering and traffic study of the site's physical characteristics and traffic conditions is necessary to determine whether a traffic signal installation is justified at a particular location. The need for signalization is based on the characteristics of several factors including, but not limited to, traffic volumes, crash history, schools, pedestrians, local needs, driver needs, construction costs and maintenance costs. The following sections provide information on the guidelines, policies, procedures and factors used by MDT to make these determinations.

12.2.1 Advantages and Disadvantages of Traffic Signals

A traffic signal is a device for the control of both vehicular and pedestrian traffic. The traffic signal exerts active control on the flow of traffic because of its predetermined or traffic-actuated assignment of right-of-way to the various movements at intersections and other roadway locations.

A traffic signal installation will operate to either the advantage or disadvantage of the persons and vehicles controlled. Consequently, it is most important that the selection and use of such a device be justified by a thorough engineering and traffic study of roadway and traffic conditions by an experienced engineer. Both the type of operation and the timing program should be assessed to determine the degree to which they can meet traffic requirements. These checks are not only valuable to the study location but are also helpful in selecting the proper equipment and operating plans of future installations.

Traffic signals, when justified, properly installed and efficiently operated, have one or more of the following advantages:

1. they provide for the orderly movement of traffic and balance the traffic handling capacity of the intersection based on demand;

2. they reduce the frequency of certain types of crashes (e.g., right-angle collisions);

3. under conditions of favorable spacing, they can be coordinated to provide for continuous or nearly continuous movement of vehicular traffic at a specific speed along a given route; and

4. they can interrupt heavy vehicular traffic at intervals to permit other vehicular or pedestrian traffic to cross.

When traffic signals are installed where they are not justified or when they have been improperly designed, ineffectively placed, inefficiently operated or poorly maintained, they can have one or more of the following consequences:

1. excessive delay to the traveling public;

2. motorists' disobedience of signal indications and disrespect for other regulations; and

3. an increase in crashes.

Section 12.2.3 presents the traffic signal warrants used by the Department, and Section 12.2.4 provides information on traffic signal needs studies.

12.2.2 Traffic Signal Study Requests

Requests for new signals and issues concerning existing signalization may be generated by many sources including the FHWA, MDT Central Office, MDT District Offices, local officials, developers and/or local citizen groups. Section 12.1.4 provides information on MDT procedures for project and plan development for traffic signal projects.

12.2.3 MUTCD Traffic Signal Warrants

The investigation of the need for a traffic signal includes an analysis of the applicable warrants contained in the MUTCD and other factors related to existing operation and safety at the study location. The following information discusses the intended application of the signal warrants that are presented in the MUTCD:

1. Eight-Hour Vehicular Volume. The following provides information on the intended application of this warrant:

    a. Condition A. The minimum vehicular volume, Condition A, is intended for application where a large volume of intersecting traffic is the principal reason to consider installing traffic signals.

    b. Condition B. The interruption of continuous traffic, Condition B, is intended for application where Condition A is not satisfied and where the traffic volume on a major roadway is so heavy that traffic on a minor intersecting roadway suffers excessive delay or hazard in entering or crossing the major roadway.

2. Four-Hour Vehicular Volume. The four-hour vehicular volume warrant conditions are intended to be applied where the volume of intersecting traffic is the principal reason to consider installing a traffic signal.

3. Peak Hour. The peak hour warrant is intended for use at locations where traffic conditions are such that for a minimum of one hour of an average day, the minor-roadway traffic suffers undue delay when entering or crossing the major roadway.

4. Pedestrian Volume. The minimum pedestrian volume conditions are intended for application where there are high pedestrian volumes and an inadequate number of gaps in the traffic stream on the major roadway.

5. School Crossing. The school crossing warrant is applicable where there are not enough adequate gaps during a crossing period in the major roadway at an established school crossing.

6. Coordinated Signal System. Progressive movement in a coordinated signal system sometimes necessitates traffic signal installations to maintain proper platooning of vehicles at intersections where they would not otherwise be needed. This is the intended application of the conditions under this warrant.

7. Crash Experience. The crash experience warrant conditions are intended for application where the severity and frequency of crashes are the principal reasons to consider installing a traffic signal.

8. Roadway Network. Installing a traffic signal at some intersections may be justified to encourage concentration and organization of traffic flow on a roadway network. This is the intended application of the conditions under this warrant.

If none of the above warrants are satisfied, then a traffic signal will not be considered at the study location. Furthermore, the satisfaction of one or more of the warrants listed above does not in itself justify the installation of a traffic signal. An engineering and traffic study of the site’s physical characteristics and traffic conditions is necessary to determine whether a traffic signal installation is justified at a particular location. See the MUTCD for the actual data, criteria and procedures that should be used to determine if a particular warrant is met.

12.2.4 Traffic Signal Needs Study

Even though one or more of the warrants presented in Section 12.2.3 may be satisfied, the results of a thorough engineering and traffic study of the site's physical characteristics and traffic conditions may indicate that the installation of a traffic signal is not the most prudent choice. A traffic signal should not be installed unless an engineering study indicates that installing a traffic signal will improve the overall safety and/or operation of the intersection. In addition to the MUTCD traffic signal warrants, the following information should be considered during the traffic signal needs study:

1. Minimum Thresholds. The MUTCD warrants are considerations for determining the need for a traffic signal. The intent of the MUTCD thresholds is to establish a minimum boundary below which a traffic signal should not be installed. Meeting or exceeding these thresholds does not automatically justify the need for a traffic signal.

2. Benefits. The benefits of the traffic signal must outweigh its disadvantages. A traffic signal should be installed only if the safety and/or the operations of the intersection or system are improved.

3. Crashes. Traffic signals are often installed to reduce certain types of crashes (e.g., right-angle collisions, pedestrian crossings). However, the installation of a traffic signal may increase the number of collisions and may fail to reduce turning conflicts between vehicles and pedestrians. Consideration should be given as to whether a change in crash types and their severity will be an actual improvement for the intersection. Crash data for the location should include at least the past three years. Consideration should be given to alternative solutions to the problem of crashes (e.g., removing parking, using advance warning signs or larger signs).

4. Geometrics. The geometric design of the intersection can affect the efficiency of the traffic signal. Installations of traffic signals at poorly aligned intersections may, in some cases, increase driver confusion and thereby reduce the overall efficiency of the intersection. If practical, the intersection should be properly aligned and have sufficient room to adequately provide turning lanes, through lanes, etc. Chapter Twenty-eight provides detailed information on the geometric design of at-grade intersections. Intersection sight distance must be maintained for flashing operation.

5. System Analysis. The control of traffic should be conceived and implemented on a systematic basis (i.e., system/route/intersection). This may sometimes result in compromises at individual intersections for the purpose of optimizing the overall

system. Traffic signals also may encourage drivers to use local facilities as alternative routes to by-pass the signal. Intersection controls should favor the major streets to move traffic through an area.

6. <u>Costs</u>. The installation and maintenance of traffic signals can be very expensive.

7. <u>Location</u>. The designer should consider the intersection relative to the land use type and density (e.g., urban, suburban, rural) and the potential for future development in the study area. The designer also should consider the location of the intersection within the context of the overall transportation system (e.g., isolated locations, interrelated operations, functional classification). Normally, isolated locations are intersections where the distance to the nearest signalized intersection or potential future signalized intersection is greater than 0.5 mile (800 m).

8. <u>Existing Signals</u>. For projects which include existing signals, it is rarely necessary to conduct a detailed study to determine if the existing traffic signal should be removed, retained or upgraded. Typically, this determination is made during the early planning phases of the project. However, if it is determined that a detailed analysis is necessary, the designer should conduct the analysis as if it were for a new signal installation. In general, the Department will consider the removal of an existing traffic signal if it no longer meets the MUTCD warrants.

9. <u>Approach Geometrics and Volumes</u>. For the purpose of comparing intersection conditions to the MUTCD warrants, the designer should count the through lanes (i.e., no auxiliary lane volumes) of the major roadway and include the auxiliary lanes and the total approach volume of the minor roadway. Additionally, engineering judgment should be used in assessing the impacts of right- and left-turning vehicles and approach lane configurations at the intersection.

10. <u>Temporary Signals</u>. The need for temporary traffic signals will be determined on a case-by-case basis. Such installations are typically considered during construction and maintenance projects. The designer should use the warrants for permanent signal installations as guidelines to determine temporary signal needs. As practical, it is desirable to design temporary traffic signals consistent with the design criteria for permanent signal installations.

11. <u>Design Year</u>. Existing volumes are typically used for warrants analyses. However, for new signalized intersections, the designer should consider the 20-year capacity of the intersection during the study. The potential for future expansion at the intersection (e.g., construction of additional approach lanes) should be assessed when determining items such as pole and pullbox locations.

12. Removal of Confusing Advertising Lights. Advertising lights, or other similar devices located adjacent to the roadway, that are similar in color to traffic signal indications could easily be mistaken for traffic signal control and interfere with the effectiveness of a traffic signal and possibly contribute to driver confusion and crashes. Where this occurs, the property owner and local officials should be contacted and the problem explained to effect a change. When this is unsuccessful, the problem should be referred to the Department's Legal Services Unit. Section 61-8-210 of the Montana Code Annotated applies in this regard.

13. Provisions for Future Installations. During the study, consideration should be given to the future needs of the study location. Any anticipated traffic growth or future operational requirements of the signalized location should be considered during planning and in the design, as practical, so that later modifications can be readily incorporated and total labor and material costs minimized. Traffic signal control equipment should have some degree of operational flexibility. This is illustrated by the following examples:

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

    b. If a signal interconnection or the need for additional vehicular turning intervals can be predicted, then provisions for these situations should be incorporated in the initial design for future implementation.

    c. If there is a roadway project and future signal installation can be anticipated, then conduits and pullboxes should be included in the project.

Chapter Forty-three will provide the designer with guidance during the data collection efforts of the study.

12.2.5 Study Report Format

The final report of the traffic signal needs study should document the results of the warrants, crash and capacity analyses and summarize the corroborating data (e.g., approach and turning movement volumes, collision diagrams). Prepare the report in a memorandum format consistent with the format presented in Section 2.1.1 in Part I of the MDT Traffic Engineering Manual. The report should be prepared for the Traffic Engineer with final approval and signature by the Traffic and Safety Bureau Chief.

The study report is the basis for the decision to install a traffic signal. It must document sufficient information to adequately justify the decision. It is therefore desirable for the report to address the following issues:

1. Study Request. The report should document why the study was requested and by whom.

2. Data Collection. The report should summarize the data and describe the data collection procedures (e.g., when vehicular and pedestrian volumes were collected). Site characteristics that would inhibit the operational potential of the traffic signal and any corrective measures should also be discussed.

3. MUTCD Warrants. An evaluation of the traffic data and its relationship to the MUTCD warrants should be included in the report. Discuss the warrants that apply to the situation under study and whether or not the conditions of the warrants are met. Figure 12.2A illustrates an example of the Department's preferred format for summarizing the results of the traffic signal warrants analysis. If one or more of the warrants are met, then further consideration may be given to signalization; however, if none of the warrants are met, then a traffic signal cannot be considered at the study location.

4. Intersection Capacity. The expected intersection capacity, level of service, delay and their relationship to existing conditions should be documented. Include an assessment of how the signalized intersection will function initially and how long it can be reasonably expected to provide adequate functionality. The report should also address the potential of perpetuating the existing form of traffic control at the study location.

5. Crash Potential. Summarize the analysis of at least three years of crash data in the report. Collision diagrams and conflicts associated with existing traffic patterns should also be documented.

6. Consideration of Other Alternatives. The report should discuss whether or not there are any realistic alternatives for addressing the situation under study short of installing a traffic signal, including the advantages and disadvantages of each.

7. Recommendations. The study report should document whether or not a traffic signal is recommended and why. It should also provide a brief discussion of specific recommendations such as:

a. Controller. Include the traffic signal controller type that would be appropriate and the advantages and disadvantages supporting the selection.

b. Signal Timing/Timing Plan. The report should briefly address the proposed signal timing and the anticipated delays and queues. The basic timing plan, if part of a system, should be described in sufficient detail to illustrate the inbound, outbound and off-peak progressions that are possible. This can also be accomplished through basic time-space diagrams.

TRAFFIC SIGNAL WARRANTS		INTERSECTION LOCATION					
		SITE 1 Maple Avenue & Main Street	SITE 2 First Avenue & Main Street	SITE 3 Grand & Main Street	SITE 4	SITE 5	SITE 6
* 1. Eight-Hour Vehicular Volume		Yes	Yes	No			
* 2. Four-Hour Vehicular Volume		Yes	Yes	No			
* 3. Peak Hour		No	Yes	No			
* 4. Pedestrian Volume		No	No	No			
* 5. School Crossing		No	No	No			
6. Coordinated Signal System		No	No	No			
* 7. Crash Experience		Yes	No	No			
8. Roadway Network		No	No	No			
Signals Warranted	Yes	Yes	Yes				
	No			No			

** Include backup data with submission.*

SAMPLE OF A TRAFFIC SIGNAL WARRANT SUMMARY FORM

Figure 12.2A

12.2.6 Responsibilities

The Department is responsible for the design and installation of traffic signals on State-maintained highways. The legal authority of Montana's public thoroughfares is established under Sections 60-1-102, 60-2-201, 61-8-202, 61-8-203, and 61-8-206 of the Montana Code Annotated. The local jurisdiction is responsible for the maintenance and operating costs of the traffic signal with reimbursement by the State if there is an agreement between the Department and the local jurisdiction. The State is responsible for the maintenance and operating costs of the traffic signal if no agreement exists.

The Electrical Unit is typically responsible for ensuring that traffic signal needs studies (e.g., warrant, capacity and crash analyses) that are associated with traffic signal installations for projects are complete. The Traffic Engineering Investigations Unit is typically responsible for conducting these studies in situations involving citizen complaints about traffic signalization. The traffic volumes needed for these studies may be obtained from the Rail, Transit and Planning Division. The Safety Management Section provides the crash data.

The Electrical Unit performs the signal design, prepares the plans and plans for the needed utility service connections. Utility movements are the responsibility of the Right-of-Way Bureau. Section 12.1.4 provides additional information on the responsibilities associated with traffic signal design projects.

12.2.7 Planning Guide for Traffic-Actuated Signal Projects

The following section presents, in outline format, a guide to assist the designer during the project when planning the installation and operation of traffic-actuated signals. While all information in this section may not be pertinent to a particular location, sufficient information is organized to provide both a catalyst and a checklist for the project.

I. Considerations Associated with Application of Traffic-Actuated Control

A. General factors affecting the type of control:

1. Relative functional classification of the intersecting roadways.

2. Number of separate phases to be controlled:

a. major traffic movements (per lane volumes).
b. number of lanes.

c. requirement for separate left-turn phase(s).
d. requirement for separate pedestrian phase(s).

3. Intersection location — isolated or near others?

   a. If now isolated, is it likely to remain so?
   b. If near others, will interconnected coordination be required?

4. Degree of variation in traffic on the intersecting streets individually or in the ratio of total traffic on the intersecting streets.

5. Selection of signal sequence.

6. Additional factors to be considered such as nearby railroad crossings, firehouses or drawbridges where signal control might be required.

B. Condition diagram (on dimensioned sketch of intersection):

1. Pavement widths.
2. Pavement type.
3. Approach grades.
4. Sidewalk locations.
5. Pavement markings (particularly stop lines and lane lines).
6. Channelization.
7. Adjoining property use and character.
8. Curb cuts (e.g., driveways).
9. Poles, type, size and location.
10. Sight line restrictions (e.g., poles, signs, trees, buildings).
11. Transit loading zones.
12. Parking regulations.
13. Existing control equipment.
14. Location of 120 V, 60 Hz AC power supply.

C. Additional data that may be useful to justify signal installation or be used for later measurement of signal effectiveness:

1. Collision diagrams and/or crash records.
2. Delay study.

II. Design of Traffic-Actuated Equipment

A. Select control requirements from traffic data; general character of intersection and previously selected sequence of operation.

B. Select type of construction; underground or overhead wiring (local criteria, existing facilities such as conduit, poles, in-place wiring).

C. Select signal head locations for best visibility.

D. Select tentative loop locations for coverage.

E. Identify requirement for additional poles for mast-arm and span-wire mounted signals. Loops and cable runs.

F. Identify routing of cable runs for connecting signals, loops and push buttons to controller assembly (cabinet). Check with utility company on poles to be used and also on location of existing underground conduit that might be available.

G. Determine number of wires required for the selected signal sequence. Allow spares. Select type of cable. Always consider possibility of future addition of signal indications or separation of signal faces.

H. Estimate length of cable runs — include:

1. Trenching underground — types of pavement or ground to be cut.
2. Up poles and between poles.
3. Allow extra for waste and minor extenuating situations.

I. Plan foundations for signal posts, poles and controller (cabinet) if base mounted type.

J. Calculate material quantities and prepare a cost estimate.

K. Coordinate with local authorities regarding construction and traffic control.

L. Review and approve electrical submittals.

III. Installation of Traffic-Actuated Equipment

A. Arrange for traffic signal turn on.
B. Install and connect controller in cabinet.
C. Set controller timing, check by observation and readjust as necessary.
D. Final inspection of traffic signal equipment.

IV. Timing the Traffic-Actuated Signal Controller

A. Division of Cycle:

1. Minimum Green.
2. Passage Time
3. Maximum Green.
4. Yellow Change Interval.
5. Red Clearance Interval.
6. Pedestrian WALK and Clearance.

B. Factors affecting Minimum Green Time:

1. Distance between inductive loop and stop line.
2. Required starting time.
3. Grade on approach to intersection.
4. Relationship of Passage Time to provide suitable Minimum Green.

C. Factors affecting Passage Time:

1. Distance between inductive loop and stop line.
2. Speed and intersection width.
3. Desired gap to permit transfer of green to waiting traffic.

D. Factors affecting Maximum Time:

1. Proportionate to peak hour distribution of traffic between phases.

2. Sum of maximum times for all phases should be of such a value to avoid excessively long cycles during peak traffic hours.

E. Factors affecting Yellow Change Intervals and Optional Red Clearance:

1. Width of intersection.
2. 85^{th} percentile speed of moving traffic.

F. Factors affecting Pedestrian Intervals, if used:

1. Width of roadway to be crossed.
2. Average pedestrian rate of travel.
3. Center islands, pedestrian signing, etc.

V. Timing the Volume-Density Controller

A. Minimum Green Time: Time to start a number of stopped vehicles and clear through intersection.

B. Added Initial Interval: Headway of vehicles clearing during green interval.

C. Passage Time: The amount of time the green interval is displayed once vehicular demand has left the inductive loop.

D. Low Limit for Passage Time (Gap Reduction):

1. Degree of forcing effect desired.

2. Number of lanes used by approaching traffic.

3. Types of detectors, for example, loop, microloop provide one actuation per vehicle.

E. Length of waiting time to reduce Vehicle Interval to low limit (Time Waiting).

12.3 TRAFFIC SIGNAL EQUIPMENT

All traffic signal equipment should meet or exceed the criteria set forth in the MDT electrical detailed drawings (contact the Electrical Unit), MDT Standard Specifications, MDT Standard Drawings, MUTCD and NEMA Traffic Control Systems. Unless inventory is depleted or there is special equipment involved, the Department typically supplies the contractor with the traffic signal controller, cabinet and signal poles (standards). Use of special equipment (e.g., automatic traffic recorder) must be approved by the Traffic Engineering Section. The following sections provide additional information on the minimum capabilities of the traffic signal equipment used by the Department.

12.3.1 Traffic Signal Controllers

Generally, the traffic signal controller is a microprocessor-based, solid-state, traffic-responsive device. The Department requires that its controllers conform to the MDT Standard Specifications and NEMA specifications and be downward compatible to the Department's existing traffic signal equipment. The following two controller types are typically used:

1. Type 4-A-SS. The Type 4-A-SS controller provides four vehicular phases, four associated pedestrian phases and four programmable phase overlaps.

2. Type 8-A-SS. The Type 8-A-SS controller provides eight vehicular phases, four associated pedestrian phases and four programmable phase overlaps.

The following briefly describes the characteristics and functionality of the traffic signal controllers used by the Department:

1. Modular Components. The basic components of the traffic signal controller are modular and can be readily integrated. These modules are also interchangeable with existing MDT controllers.

2. Serial Communications. The traffic signal controller has a serial communications port capable of uploading and downloading information and supporting modem and system communications.

3. Internal Time Clock. The internal time clock of the controller is used to enable output selections (e.g., coordination, flash, dial, split, offset, special functions). Timing is accomplished by digital methods and uses the 60-Hz power-line frequency as a reference basis.

4. Internal Coordinator. The controller's internal coordinator can be used as either a master or a slave with inputs and outputs for six dials, three splits and five offsets. Coordination does not interfere with non-coordinated signal operation.

5. Controller Phase Capabilities. Each phase within the controller has identical control capabilities (features and options) that can be exercised independently among the available phases. Timing intervals and phase options are programmable; see Item 7.

6. Information Display. The front panel of the controller can display the status of the following information:

   a. presence of vehicular calls and actuations on each phase,
   b. presence of pedestrian calls on each phase,
   c. termination of phase because of gap-out,
   d. termination of phase because of maximum time-out or force-off,
   e. maximum 2 in effect,
   f. phase timing,
   g. phase next,
   h. interval timing,
   i. time remaining in interval,
   j. hold in effect,
   k. controller at rest, and
   l. preemption.

7. Programmable Functions. Programmable functions are available and each function's status can be displayed on the front panel of the controller, including:

   a. phases and overlaps that are to be enabled for the specific intersection configuration,

   b. interval timing parameters,

   c. Emergency vehicle and/or railroad pre-emption routines,

   d. coordination parameters and time-of-day operation plan,

   e. vehicle detection parameters, and

   f. start-up sequence.

   For additional functions, see the manufacturer's manual.

Previously programmed data that is stored in the controller can be displayed from the unit's front panel. The parameter called for and its current programmed value can be displayed without interruption of the cyclic operation of the traffic signal controller. In addition, it is possible to change programmed values while the controller is operating

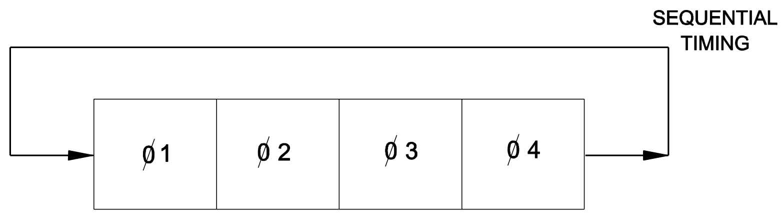
8. Overlap Programming. Overlaps may be programmed (i.e., assigning the overlap to the respective phases) through the use of either a NEMA overlap card or the front panel of the controller.

9. Ring Configuration. Either single-ring or dual-ring control may be used depending on the number of phases needed. Single-ring control is used where the conflicting phases are established in a set order. Figure 12.3A(a) illustrates the appropriate phasing sequence for a four-phase, single-ring controller. For dual-ring control, two interlocking rings are arranged to time in a preferred sequence and to allow concurrent time of both rings, subject to the restraint of the barrier. For the controller to advance beyond the barrier, both sets of rings must cross the barrier line at the same time (i.e., no conflicting phase may be shown at the same time). Figures 12.3A(b) and 12.3A(c) illustrate typical phase sequences for the eight-phase, dual-ring controller. There are additional phase sequence options with the eight-phase controller. See the manufacturer's manual for other options.

10. Type of Controller Operation. The traffic signal controllers that are used by the Department can be assembled and configured to operate as follows:

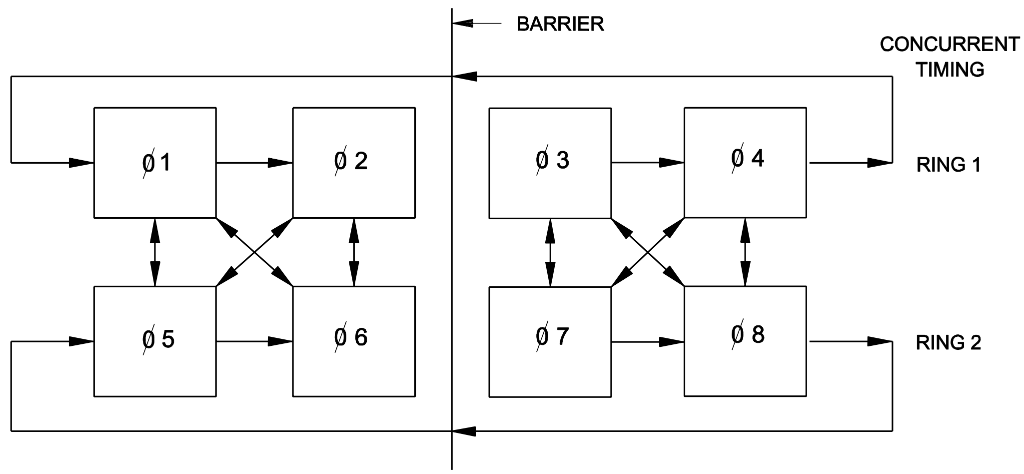
    a. pretimed control,
    b. semi-actuated control,
    c. full-actuated control, or
    d. actuated with volume-density control.

    The type of controller operation that is selected for the study location will be determined on a case-by-case basis. Additional information on the types of traffic signal controller operation is discussed in Section 12.3.2.



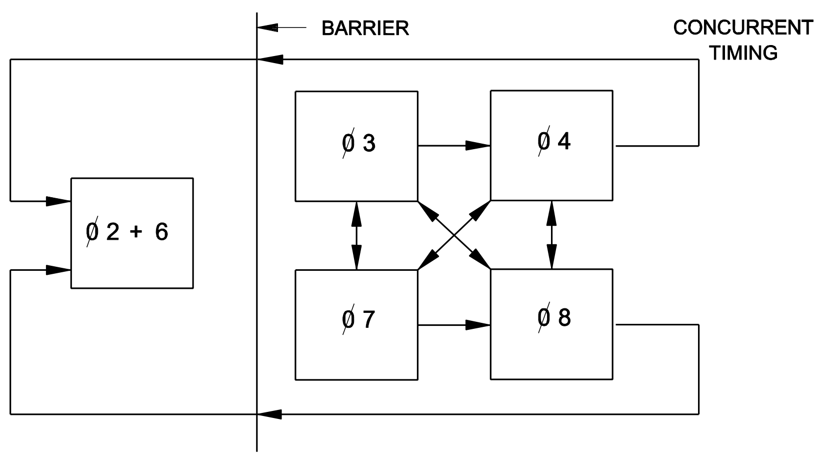
4- PHASE UNIT

(a) SINGLE-RING CONTROLLER UNIT



8-PHASE UNIT

(b) DUAL-RING CONTROLLER UNIT



8-PHASE UNIT OPERATING AS A 5-PHASE UNIT

(c) SPECIAL APPLICATION OF DUAL-RING CONTROLLER UNIT

SEQUENCE OF PHASES

Figure 12.3A

12.3.2 Traffic Signal Controller Operation

A traffic signal controller is a solid-state, electrical device for controlling the sequence and phase duration of the traffic signal indications. Right-of-way is assigned by turning on or off the red-yellow-green indications. There are two basic types of traffic controllers — pretimed and traffic-actuated. The Department's controllers have the ability to simulate several operational modes of traffic signal control — pretimed, semi-actuated, full-actuated and actuated with volume-density control. Under pretimed control, the controller operates according to predetermined schedules. Under traffic-actuated control, the controller operates with variable vehicular and pedestrian timing and phasing intervals that are dependent upon traffic demands. If there is no demand for a phase under traffic-actuated control, the controller may omit that phase in the cycle (e.g., if there is not a demand for left turns, then the signal indications associated with the left-turn phase will not be displayed). The following sections provide general guidance on traffic signal controller operation. Section 12.4 describes the phasing and timing aspects of the traffic signal controller.

12.3.2.1 Pretimed Versus Traffic-Actuated Control

The decision to use either pretimed or traffic-actuated control should be made only after a review of the relative merits and adaptability to the particular study location. The following discussion presents the basic differences in these two types of control as related to their operating characteristics and suitability to various traffic requirements.

12.3.2.1.1 Pretimed Control

With basic pretimed control, a consistent and regularly repeated sequence of signal indications is given to traffic. The cycle length required for a complete sequence of indications typically ranges from 60 to 120 seconds. Control can be programmed to accommodate different timing plans based on the time of day and/or day of week. Pretimed control is best suited to locations where traffic patterns are relatively stable or where traffic variations can be accommodated by a pretimed schedule without causing unreasonable delays or congestion. It is particularly adaptable to locations where signal coordination is desired. The designer should consider the following factors on pretimed control:

1. Coordination. Consistent starting time and duration of intervals of pretimed control facilitates coordination with adjacent traffic signals and provides more precise coordination than does traffic-actuated control, especially in a grid system of a downtown urban area. This coordination permits progressive

movement and a degree of speed control through a system of several well-spaced traffic signals. Coordination promotes maximum efficiency in the operation of two or more very closely spaced intersections.

2. Traffic Fluctuation. Pretimed control cannot compensate for unplanned fluctuations in traffic flow, which can cause excessive vehicular delays. It also tends to be inefficient at approaches with random traffic arrivals (e.g., isolated intersections).

3. Detector Independency. For proper operation, pretimed control is not dependent on the movement of approaching vehicles past detectors. Thus, operation is not adversely affected by conditions preventing normal movement past a detector (e.g., stopped vehicle, poor weather conditions).

4. Pedestrian Volumes. Pretimed control may be more acceptable than traffic-actuated control in areas where large and fairly consistent pedestrian volumes are present and where confusion may occur as to the operation of pedestrian push buttons.

5. Equipment Costs. Generally, the installed cost of equipment necessary for pretimed control is less than that needed for traffic-actuated control.

12.3.2.1.2 Traffic-Actuated Control

Traffic-actuated control differs from pretimed control in that the cycle length is not fixed. The cycle length and the sequence of intervals may or may not remain the same from cycle to cycle. In some cases, certain phases may be omitted when there is no actuation or demand from waiting vehicles or pedestrians. At intersections where traffic volumes are unpredictable and fluctuate widely and irregularly, where traffic demands shift frequently, or where interruptions to main-street flow must be minimized, maximum efficiency in signal operation may be attained by the use of semi- or full-actuated control. The designer should consider the following factors on traffic-actuated control:

1. Traffic Fluctuation. Traffic-actuated control may provide greater efficiency at intersections where fluctuations in traffic cannot be anticipated and programmed for under pretimed control.

2. Intersections with Minor Streets. At the intersection of a major street and a minor street, semi-actuated control assigns priority to the major street. This is accomplished by keeping interruptions to the major street to the minimum time required to satisfy the minor street vehicular or pedestrian demand.

3. Progressive Systems. Semi-actuated control may increase the efficiency at intersections located within progressive systems where interruptions of major street traffic are undesirable and must be held to a minimum frequency and duration. A background cycle is superimposed upon the operation to effect coordination with nearby signals.

4. Isolated Intersections. At the intersection of a major street and a minor street, semi-actuated control should be used. At the intersection of two major roadways, full-actuated control should be used to decrease unnecessary delay to traffic. In either case, the predictability of the traffic determines the type of operation to be used.

5. Periodic Need for Signalization. Semi-actuation is particularly applicable at locations where signal control is needed for only brief periods of the day (e.g., school crossing signals).

12.3.2.1.3 Other Factors Governing Control Selection

The decision between pretimed and traffic-actuated control frequently considers initial equipment cost, installation cost and anticipated operating expenses (e.g., pretimed control is generally less expensive to install and maintain than other types of control). However, the designer should also consider the following factors in making the final determination:

1. Economic Considerations. Careful attention should be given to economic benefits or losses that may accrue to motorists and pedestrians. Unnecessary stoppages and delays to traffic movement result in economic losses which accumulate to a significant total during the life of the traffic control equipment. In many cases, the reduction in motor-vehicle operating costs will justify installation of signal control equipment that has a higher initial cost but greater efficiency in handling traffic.

2. Crash Potential. Crash hazards also should be considered. While signals are most effective in reducing right-angle collisions, they tend to increase the frequency of rear-end collisions. There is an increased crash potential with an increased number of stops. Possible reduction of crashes through efficient operation of traffic signals frequently will offset added signal installation and maintenance costs.

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

12.3.2.2 Semi-Actuated Control

Semi-actuated control is based on vehicular detection from one or more approaches, but not on all approaches. Typically, vehicular detectors (e.g., inductive loops) are placed only on the minor approaches where traffic is light and sporadic. The major approaches are kept in the green phase until a vehicle on the minor approach is detected. If there is a demand on the minor approach and the minimum green time for the major approach has elapsed, the right-of-way will then be given to the minor approach. To handle various fluctuations on the minor approach, the minor approach is given enough time to clear one vehicle with additional time added for each new detection up to the maximum green time. Once the minor approach demand has been satisfied or when the maximum green time has been reached, the right-of-way is then returned to the major approach and the cycle begins again. If there is no minor approach demand, the major approach will remain in the green phase indefinitely. Typical locations for semi-actuated control include:

1. major routes intersected by roadways of lower functional classification,
2. school crossing intersections,
3. on access routes to industrial areas or shopping centers,
4. on access routes to recreational areas or sport centers,
5. on cross streets with poorly spaced signals along the major route, and/or
6. on cross streets with minimal traffic volumes.

The following presents some of the advantages and disadvantages of semi-actuated control:

Advantages

1. Maximizes capacity and minimizes stops and delays on the major roadway while still servicing the side street.

2. Semi-actuated control can be easily incorporated into a coordinated system. By means of auxiliary devices, semi-actuated control can be coordinated with traffic signals at adjacent intersections, although this coordination is not usually as precise as with pretimed control (e.g., early release of traffic from semi-actuated intersection, dropping out of coordination to serve pedestrians crossing extremely wide roadways).

3. Semi-actuated control can be effectively used at isolated intersections.

4. It tends to provide the maximum efficiency at intersections where fluctuation in the side street traffic cannot be anticipated and programmed for with pretimed control.

5. Different non-conflicting phases can operate concurrently under semi-actuated control.

Disadvantages

1. A detection device is required, typically inductive loops, on the minor street.
2. There is no dilemma zone protection for any of the approaches.

The major operating features of semi-actuated control are as follows:

1. Detection of the actuated or side street phase only.

2. Arterial or major street receives guaranteed minimum right-of-way time.

3. Right-of-way is retained on the major street indefinitely until termination is caused by demand on an actuated phase.

4. Actuated phase receives right-of-way after demand, provided guaranteed minimum green time has been supplied to the arterial.

5. Actuated phase has minimum green.

6. Actuated phase right-of-way is extended by additional actuations until preset maximum is reached.

7. Controller “Memory” feature remembers if actuated phase right-of-way is terminated at the maximum and returns right-of-way to actuated phase after guaranteed minimum right-of-way time has been provided on the major phase, if demand is present.

8. Timing controls to preset Yellow Change intervals for both phases.

9. Red Clearance intervals are provided in most applications.

10. Concurrent pedestrian intervals may be provided on the arterial and selective response to pedestrian demand on the side street.

12.3.2.3 Full-Actuated Control

Full-actuated control employs detection devices on all approaches to the signalized intersection. The green interval for each street or phase is determined on the basis of volume demand. Continuous traffic on one street is not interrupted by an actuation demand from the side street until a gap in the traffic appears or when the preset maximum green time has elapsed. Once the minor street demand has been satisfied, right-of-way is typically returned to the major street whether or not a major street detection has been registered. Where there is a continuous demand on all approaches, the intersection tends to operate as a pretimed system. Full-actuated control is an appropriate design choice:

1. at isolated locations where volumes on intersection legs are more equal with sporadic and varying traffic distribution, and/or

2. at locations where there are high-speed approaches and where there is a potential to successfully mitigate “dilemma zone” problems; see Section 12.4.8.

The following presents some of the advantages and disadvantages of full-actuated control:

Advantages

1. It is very efficient at isolated intersections with identical roadway functional classification.

2. It can handle varying traffic demands (e.g., complex intersections where more than one movement is sporadic or subject to variation in volume).

3. Different non-conflicting phases can operate concurrently under full-actuated control.

Disadvantages

1. A detection device is required on all approaches, typically inductive loops.
2. It is typically more complex to operate and maintain.
3. The number of stopped vehicles is heaviest under this type of control.

The major operating features of full-actuated control are as follows:

1. Detectors on all approaches to intersection.

2. Each phase has preset minimum green that allows standing vehicles to start and enter the intersection.

3. Right-of-way time is extended by each actuation during extendible passage period commencing at the same time as the minimum green.

4. The length of the phase is limited by preset maximum green.

5. Yellow Clearance intervals are preset for each phase.

6. All Red Clearance intervals are preset for all phases.

7. Pedestrian demand may be provided on all phases.

8. The operating mode for each phase may be programmed to modify phase control as follows:

    a. Lock Detection. Memory of vehicle demand locked into controller until phase is served.

    b. Presence Detection. Memory of vehicle demand only while vehicle present in detection zone.

    c. Minimum Vehicle Recall. Vehicle right-of-way automatically reverts to selected phases at every opportunity.

    d. Pedestrian Recall. Vehicle and pedestrian right-of-way automatically reverts to selected phase at every opportunity.

    e. Vehicle Recall to Max. Vehicle right-of-way automatically reverts to selected phases at every opportunity and times to maximum.

    f. Non-Actuated. Phase automatically operates in semi-actuated mode providing vehicle and pedestrian right-of-way.

12.3.2.4 Actuated with Volume-Density Control

The density feature is an enhancement to the actuated controller. Additional detectors are placed in advance of the intersection to determine both the number of vehicles waiting and vehicular gaps. The density feature allows the controller to adjust the initial portion of the green time to account for the queue of waiting vehicles arriving during the yellow and red phases to clear the intersection. Once the initial queue is cleared, the allowable mainline vehicular gap is reduced over time giving greater priority to conflict calls from the side streets. When the gaps on the mainline are too long or the preset maximum green time has passed, the right-of-way is then given to the side streets to allow the waiting vehicles a chance to enter or cross the highway. The following presents some of the advantages and disadvantages of the volume-density control:

Advantages

1. Volume-density control is very efficient at high-speed intersections.
2. It can effectively handle large traffic volumes.
3. It can effectively clear stored traffic (e.g., stored vehicles in a left-turn bay).
4. It can accommodate a higher priority on the mainline.
5. Volume-density control can also allow different non-conflicting phases to operate concurrently.

Disadvantages

1. Additional detection devices are required.
2. Volume-density control is more complex to operate.
3. Typically, it has higher initial costs.

The major operating features of volume-density control are as follows:

1. Detectors on all phases.
2. Each phase has an assured right-of-way or green time as determined by programming of the following:
    a. Minimum Green,
    b. number of seconds assigned to each vehicle which arrives during non-green time on a phase, and
    c. Passage Time.

3. Passage Time is the extension time unit after the assured (Minimum) green has elapsed. This time is programmed for the time required for a vehicle traveling at the 85th percentile speed to go from the inductive loop to the intersection. This time interval can be reduced to a predetermined low limit of Passage Time when vehicles have waited for a preset time against a red signal. This is known as Time Waiting-Gap Reduction.

4. The Maximum time limits green extension. If the controller is efficiently timed, this feature seldom terminates the right-of-way because of the reduction factor affecting the Passage Time.

5. Yellow Change and Red Clearance intervals are preset for each phase.

6. The operating mode of each phase can be programmed in the same manner as described for the full-actuated controller (i.e., Minimum Vehicle Recall, Non-Lock Detector).

12.3.2.5 Pedestrian Feature

The pedestrian feature of the traffic signal controller allows for the timing of the WALK and DON’T WALK symbol-display intervals and can be actuated by pedestrian push buttons or other approved detectors. The following presents some of the advantages and disadvantages of using the pedestrian feature:

<u>Advantages</u>

1. It provides specific intervals for pedestrian crossings.

2. Where there is minimal pedestrian demand, disruption to the vehicular phases can be minimized.

<u>Disadvantages</u>

1. Pedestrian intervals concurrent with green time may marginally delay right-turning vehicles.

2. In coordinated signal systems, minor street pedestrian intervals can significantly decrease the green band on the major street.

12.3.2.6 Specialty Features

There are several other special operational capabilities of the traffic signal controller that may be used in traffic engineering designs (e.g., flashing beacons, emergency vehicle actuations, railroad grade-crossing signals). The use of these features is site specific and should be used on a case-by-case basis.

12.3.3 Auxiliary Controller Equipment

In a traffic signal controller, the controller has a very specific function, but the controller is not complete without the necessary auxiliary equipment (e.g., power supply, surge protectors, load switches, etc.). The MDT Standard Specifications provides detailed information on this equipment. The followings sections briefly describe the critical auxiliary controller equipment that is typically used by the Department.

12.3.3.1 Load Switches

Load switches are solid-state devices that act on the low-voltage outputs of the controller to switch on and off the electrical current to the lamps in the signal heads. Typically, eight load switches are supplied with the Type 4-A-SS, four-phase controller and twelve load switches are supplied with the Type 8-A-SS, eight-phase controller. Load switches must meet NEMA requirements as specified in the MDT Standard Specifications.

12.3.3.2 Flasher and Flasher Relays

The controller cabinet is wired to accept a solid-state flasher and flash transfer relays. The cabinet has program flash jumpers to allow any combination of flashing red or yellow signal indications. The following briefly describes this equipment:

1. Flasher. The flasher is a solid-state electronic device that produces between 50 and 60 signal indication flashes per minute with equal on and off time intervals. The flasher must meet all NEMA Type 3 requirements and conform to the criteria presented in the MUTCD.

2. Flasher Relay. The flash transfer relay(s) are located within the controller cabinet in close proximity to the load switches, flasher and signal field terminals. During flashing mode, the coil of the flash transfer relay is energized and the

controller is electrically isolated from the signal-lamp circuits. The flash circuit is not controlled by the controller, except during programmed flash operations.

12.3.3.3 Conflict Monitor

There is a potential for the accidental display of erroneous indications (e.g., green indications for conflicting movements). Typically, the problem will be with the solid-state load switch, which switches the electrical current to the signal indications on and off; see Section 12.3.3.1. To protect against failure, all solid-state controllers must have a conflict monitor. Conflict monitoring devices exist to monitor many different types of traffic signal controller problems. Many of the references presented in Section 12.1.3 describe these devices. The following presents the conflicts that are typically monitored by the equipment used by the Department:

1. Channel-to-Channel Conflict Monitoring. This type of conflict monitoring protects against the display of green, yellow or WALK symbol-display indications on conflicting movements. The conflict monitor is programmed so that, upon sensing any conflicting combination of signal indications, the monitor will place the intersection in its flashing mode. The device senses the presence of voltages on the inputs to determine if a conflict exists. Should two incompatible channels have voltages at a level sufficient to even dimly illuminate a signal lamp for a duration exceeding one-half second, the monitor will trigger the flashing mode. This will protect not only against the failure of a load switch or a controller, but also against a short circuit in field wiring.

2. Absence-of-Red Monitoring. The conflict monitor is designed to check for the absence of a display output on any one channel by monitoring the voltages on each channel's inputs. The function's logic is that if green is not on, and yellow is not on, then red should be on. If not, a problem is assumed, and the intersection is placed into flashing mode. This feature does not protect against the absence of a red indication on a movement caused by a burned-out bulb or broken signal wiring.

3. Burned-Out-Bulb Protection. The conflict monitor will trigger and indicate a channel-to-channel conflict message if all yellow, green or WALK symbol-display bulbs on a channel burn out (i.e., the filament breaks). This situation is caused by a quirk in the design of solid-state load switches and is frequently a problem where single display heads are used (e.g., on a left-turn phase display). A loading resistor is typically required on all single-display green-indication lamps to avoid placing the intersection into a flashing mode for this non-critical condition.

The conflict monitors in use by the Department also monitor switch fail conditions, inadequate yellow timing and have serial communications for a printer or computer. A 6-Channel Conflict Monitor is used with the Type 4-A-SS controller and a 12-Channel Conflict Monitor is used with the Type 8-A-SS controller.

12.3.3.4 Detector Amplifiers

Detector amplifiers are externally powered, solid-state digital devices that are used in conjunction with inductive loops for traffic-actuated control. They are rack mounted in the controller cabinet and monitor the change in inductance of the loop. The change in inductance causes a normally-closed relay to de-energize and place a call to the controller. Because the relay is held in the energized state, a loss of power will close the contacts and place a constant call to the controller. The Department typically uses two-channel detector amplifiers. Typically, four detector amplifiers are supplied with the Type 4-A-SS controller and eight with the Type 8-A-SS controller.

12.3.3.5 Preemption Systems

Preemption is the modification of a traffic signal's normal operation to accommodate a special occurrence, such as the approach of an emergency vehicle, the passage of a train through a grade crossing or the opening of a drawbridge. Another form of preemption can also be used to provide priority to transit vehicles by minimizing the delays to these vehicles. Railroad preemption sequences should be shown in the plans. For information on preemption equipment, the designer should contact the manufacturer. The following describes several situations where preemption is typically used:

1. Railroad-Crossing Preemption. Where a signalized intersection is within 200 ft (60 m) of a railroad grade crossing, preemption is used to eliminate the potential for conflicting instructions from the railroad crossing signals and the intersection signals. Where a highway-rail grade crossing is located within 50 ft (15 m), or within 75 ft (23 m) for a highway that is regularly used by multi-unit vehicles, of an intersection controlled by a traffic signal, the use of pre-signals to control traffic approaching the grade crossing should be considered. Section 12.7, the MUTCD, and the ITE publication Preemption of Traffic Signals At or Near Railroad Grade Crossings with Active Warning Devices describes several preemption strategies and define the requirements for grade-crossing preemption.

Railroad preemption requires interconnection between the traffic signal controller and the grade-crossing signal equipment. The preemption routine at the traffic signal controller is initiated by the approach of a train, as detected by the railroad's controller, and typically starts with a short "track clearance" phase, to clear motorists who may be stopped between the railroad crossing stop line and the intersection. Subsequent signal displays include only those that would not be in conflict with the occupied grade crossing. When the train has passed, the signal is returned to normal operations. On State routes, this type of preemption typically requires an agreement between the State and the railroad. The MUTCD provides additional guidance on vehicular and pedestrian signal indications when a signalized intersection is preempted by a train.

See Section 12.7 for additional information on highway-railroad crossing signals.

2. <u>Firehouse/Fire Route Preemption</u>. There are several forms of firehouse or fire route preemption; the common denominator for this category is the actuation of the preemption sequence at some fixed point (e.g., direct wired with a push button located within the firehouse).

   The simplest form of firehouse preemption is the installation of an "emergency signal," typically at the firehouse driveway intersection with a major through street. Using essentially a 2-phase, semi-actuated controller, the signal dwells in the through-street display (i.e., green) until called by an actuation in the firehouse. The signal then provides a timed right-of-way to the driveway to allow emergency vehicles to enter or cross the major street.

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

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

3. <u>Emergency-Vehicle Preemption</u>. A number of devices are available to permit the preemption of signals by moving emergency vehicles. In each case, the preemption equipment causes the signals to advance to a preempt movement display. On State routes, this type of preemption typically requires an agreement between the State and the appropriate local governmental agency.

One system of identifying the presence of the approaching emergency vehicle uses a light emitter on the emergency vehicle and a photocell receiver for the approach to the intersection. The emitter outputs an intense strobe light flash sequence, coded to distinguish the flash from lightning or other light sources. The electronics package in the receiver identifies the coded flash and generates an output that causes the controller to advance to the desired preempt sequence. The Department uses infrared emergency preemption systems. Two detectors are typically used with the Type 4-A-SS controller and the Type 8-A-SS controller. The MDT Standard Specifications provide additional information on these detectors as well as how to assemble and wire the system within the controller cabinet.

A second type of system uses a low-power radio transmitter on the emergency vehicle and a radio receiver at each intersection to be preempted. The driver of the vehicle activates a dashboard switch based on the heading of the vehicle — north and south or east and west. This switch codes the radio transmission, and the intersection receiver can implement the appropriate preempt sequence. One system using this technique includes a compass-based switch in the emergency vehicle. It can also encode the vehicular identification number for preemption logging purposes. Both the optical and the radio systems require a specialized transmitting device on each vehicle for which preemption is desired, and they require that drivers activate the transmitters during their run and turn off the transmitters after arriving at the scene.

A third system uses a receiver at the intersection that senses the emergency vehicle's siren to initiate preemption. It can be used to start a predetermined preemption sequence or intersection flash.

4. Transit Vehicle Preemption. Most transit-preemption systems are designed to extend an existing green indication for an approaching bus and do not cause the immediate termination of conflicting phases, as would occur for emergency vehicle preemption. On State routes, this type of preemption typically requires an agreement between the State and the appropriate local governmental agency.

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

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

5. Preemption Equipment. With microprocessor-based controllers, virtually all preemption routines are performed by the controller software. The only necessary external equipment is the preemption call detection device. In controllers built to NEMA standards, internal preemption capability is provided as an option and requires a special module. Several manufacturers provide a set of preemption routines that can be tailored to virtually any intersection's preemption scheme. Others may require a factory-designed sequence, burned into memory for the requirements of a specific intersection.

12.3.4 Traffic Signal Controller Cabinet

Controller cabinets are enclosures designed to house the controller and its auxiliary equipment (e.g., load switches, flasher, detector amplifiers, conflict monitor, emergency preemption discriminator, transient voltage protector), providing for its security and environmental protection (e.g., weatherproof). The Department uses NEMA Type 3R rated cabinets. All controller cabinets must meet the criteria in the MDT Standard Specifications including material type, size, lock, police door, outlet, ventilating fan, vents, internal light and heater, wiring, etc. Section 12.4.2 presents considerations for the placement of the cabinet relative to roadside safety. The following discusses the various cabinet types used by the Department:

1. "H" Cabinet. The "H" cabinet is pole-mounted and wired for six load switches (i.e., four vehicular and two pedestrian). In general, the Department no longer uses this cabinet due to its limited size. However, this cabinet type may be used, if practical, for matching or upgrading existing local signals or when existing right-of-way constraints prohibit controller pedestals.

2. "M" Cabinet. The "M" cabinet is pedestal-mounted and wired for nine load switches (i.e., four vehicular, four pedestrian and one overlap). This cabinet is used with the Type 4-A-SS, 4-phase controller. Where there is a possibility that more phases may be necessary in the future, the "P" cabinet should be used.

3. "P" Cabinet. The "P" cabinet is pedestal-mounted and wired for fourteen load switches (i.e., eight vehicular, four pedestrian and two overlap). Its size will accommodate the Type 8-A-SS, 8-phase controller; and, if used with the Type 4-A-SS, 4-phase controller, it allows for a future upgrade if necessary. "P" cabinets are also used for system masters.

12.3.5 Detectors

12.3.5.1 Detector Operation

The purpose of a detector is to determine the presence of a vehicle, bicyclist or pedestrian, or the passage of a moving vehicle. This detection is sent back to the controller which adjusts the signal accordingly. There are many types of detectors available that can detect the presence or passage of a vehicle. Inductive loops and video detection systems are the two types of detection systems typically used by MDT in its signal designs. Both detection systems can be used for passage or presence detection, conduct vehicular counts and help determine the speed of passing vehicles. Although inductive loops are the most prevalent detection system used within the state, video detection systems are being deployed as an alternative to the inductive loop. As new technology is developed for the detection of vehicular traffic, its use must be approved by the Traffic Engineer and coordinated with the District to detail any special maintenance requirements or equipment needs prior to its use.

In most cases, the controller detection device can operate in several different modes. The following discusses several of these modes:

1. Pulse Detection. Pulse detectors detect the passage or movement of a vehicle over a given point. They submit a short-duration (pulse) output signal. The single-loop design (short detection area) is considered as a passage detector.

2. Presence Detection. Presence detectors register an actuation when a vehicle is stopped or is within the detection area. A signal output is generated for as long as the detected vehicle is within the monitored area (subject to the eventual tuning out of the call by some types of detectors). The multiple-loop design (long detection area) is used for presence detection.

3. Locking Mode. The detector or the controller holds a call in the waiting phase until the call has been satisfied by a green display even though the calling vehicle may have already vacated the approach (e.g., vehicle turning right on red).

4. Delayed Detection. Delayed detection requires the vehicle to be located in the detection area for a certain set time before a call is recorded. If a vehicle leaves the area before the time limit is reached, no call is noted. This application is appropriate where right-turns-on-red are allowed.

5. Extended or Stretch Detection. With extended detection, the call is held even after a vehicle has left the detection area. This operation is typically performed to hold the call until the passing vehicle has time to reach a predetermined point beyond the detection zone. With solid-state controllers, the extended detection is typically handled by the controller software.

Where the controller is part of a coordinated signal system design, special care will be required when using extended or delay detection to ensure that the local controller will not adversely affect the timing of the system.

12.3.5.2 Inductive Loop Detection

An inductive loop design consists of four or more turns of wire encased in a non-conductive conduit embedded in the roadway. As a vehicle passes over the loop, it disrupts the magnetic field created by the current running through the wire. This disruption is recorded by a detector amplifier and is transmitted to the controller as a vehicle call. NEMA criteria define the requirements for both self-contained units (shelf mounted) and for card type detector units (inserted into a multi-slotted card rack wired in the cabinet). The NEMA criteria also define optional timing features that can be used for inductive loops, including delay or extension of the detector output. The correct use of these features requires an additional green sense harness to be installed in the traffic signal control cabinet. MDT’s standard traffic signal cabinets do not monitor the green/yellow outputs from the controller. Instead, the delay and extend features are typically incorporated within the traffic signal controller, not the loop detector:

The advantages of inductive loops are:

1. They can accurately detect vehicles in all weather conditions.
2. They can be designed as a system of loops to meet various site conditions.
3. When installed correctly, they provide a service life of greater than ten years.
4. Loop detectors are relatively inexpensive to replace.
5. They are a cost effective way to detect vehicles.

The following disadvantages are also associated with inductive loops:

1. They cannot reliably detect bicycles or motorcycles.

2. They are susceptible to damage caused by typical roadway work (e.g., milling, re-construction activities).

3. Once installed, the detection zone cannot be changed.

4. Replacement of a failed inductive loop requires intrusion in the roadway causing disruption to the traveling public due to lane closures, and a degradation of the roadway surface due to the subsequent cutting of the roadway.

5. Replacement of a single failed loop is difficult when the loop is configured as a system of loops on an approach and will typically require multiple loops to be replaced.

The MDT electrical detail drawings illustrate typical loop layouts and installation. The designer needs to be aware that the typical layouts shown in the electrical detailed drawings are for illustrative purposes only. Each intersection should be designed individually to meet local site conditions.

A sequence of loops may be used at the intersection itself for presence detection of vehicles stopped at the stop line of the signalized intersection. A set of loops before the intersection may be used to determine the passage of vehicles. The distance from the stop line to these loops is typically based on the posted speed limit. Section 12.4.8 provides additional information on detector locations.

12.3.5.3 Video Detection System

The video detection system consists of a video camera and a microprocessor card (video processor) similar to the detector amplifier used with inductive loops. The video camera is typically installed on the traffic signal mast arm or luminaire mast arm immediately opposite the approach to be detected. The camera requires 120 v AC power to be run from the traffic signal control cabinet to the camera to power the camera, provide power to a defroster to keep the lens clear during inclement weather, utilize the auto-iris to adjust for poor lighting conditions, and to focus and zoom the camera. The video image is typically brought back to the traffic signal cabinet using a coaxial cable suitable for underground installation. The cable required for power and the coaxial cable required for the video are typically manufactured as a Siamese cable, meaning they have been placed within one jacket, or outer covering, to help with the installation.

The video image is input to the video processor. After ensuring the video image is of appropriate size and quality, detection zones are "drawn" on the image and signify the location a vehicle must pass through in order for it to be detected. The video processor learns the background image of the camera and monitors the detection zones. Each detection zone is broken into pixels to further distinguish between the background image and a vehicle. When a significant number of pixels within the detection zone have changed, the processor assumes a vehicle has entered the detection zone and places a vehicle call on the controller.

NEMA criteria define the requirements for both self-contained units (shelf mounted) and for card type detector units (inserted into a multi-slotted card rack wired in the cabinet). Similar to the inductive loop detectors, the video processor has optional timing features that can be used for delay or extension of the detector output. As with the inductive loop detector, the correct use of these features requires an additional green sense harness to be installed in the traffic signal control cabinet. Therefore, the delay and extend features are typically incorporated within the traffic signal controller, not the video processor card.

The advantages of video detection systems are:

1. They can reliably detect small vehicles including bicycles and motorcycles.
2. Properly designed, one camera and one processor can detect an entire approach.
3. They are not susceptible to damage caused by typical roadway work (e.g., milling and re-construction activities).
4. Once installed, the detection zone can easily be changed due to changes in lane configuration or temporary traffic control changes.
5. Replacement of failed cameras or processors requires no intrusion in the roadway and has minimal impact on the traveling public.

The following disadvantages are associated with video detection systems:

1. They cannot detect vehicles in poor visibility due to severe weather (e.g., thick fog, heavy rain, heavy snowfall).

2. They have a higher tendency for placing false calls due to shadows, changing roadway conditions (e.g., wet pavement, snow covered roadways) and poor lighting conditions.

3. The expected service life is approximately 5-10 years.

4. The video processor cards are expensive to replace.

5. Video detection systems require additional programming and technical expertise to install.

Video detection systems are typically used for presence detection of vehicles stopped at the stop line of the signalized intersection. Although video detection could be used to determine the passage of vehicles before the signalized intersection, it is usually cost prohibitive when compared to the inductive loop.

12.3.5.4 Other Detector Types

There are numerous types of vehicular detectors available. The following discusses several other detector types that are available:

1. <u>Microloop Detector</u>. A microloop detector is similar to the magnetometer detector (see Item 3.), but it can work with the standard electronic units used for inductive loops. A typical microloop installation in pavement is illustrated in the MDT electrical detailed drawings. A major disadvantage of the microloop detector is that it requires some motion to activate the triggering circuitry of the detector and does not detect stopped vehicles. This type of detector typically requires two detectors placed side-by-side due to its limited field of detection.

2. <u>Microwave Detector</u>. A microwave detector is a microprocessor controlled vehicle detector mounted above traffic to detect moving vehicles. The detector emits microwave energy (a radio frequency of approximately 10 GHz) at the oncoming traffic. The microprocessor analyzes the reflected microwave energy to determine motion. Once motion is sensed, the detector closes a set of normally open contacts and places a call to the controller. One of the major advantages of this type of detector is that it is unobtrusive to the roadway pavement and is easily accessible for maintenance. A major disadvantage of the microwave detector is its ability to detect the presence of a stopped vehicle which, in turn, causes the controller to be on locking detection.

3. Ultrasonic Detector. An ultrasonic detector is a microprocessor controlled vehicle detector mounted above traffic to detect the presence of a vehicle. The detector transmits a burst of ultrasonic energy (a radio frequency of approximately 50 kHz) at a point directly below the detector. If an object is present, some of the energy is reflected back and detected. Once an object is detected, the detector closes a set of normally-open contacts and places a call to the controller. Like the microwave detector, the ultrasonic detector is unobtrusive to the roadway pavement and is easily accessible for maintenance. One of the downfalls of this detector is it must be mounted directly over the area to be detected. It also has a limited field of detection of approximately 4 ft (1.2 m).

12.3.5.5 Pedestrian Detectors

The most common pedestrian detector is the pedestrian push button, which should be installed, if warranted, based on the results of an engineering study. Other types of pedestrian detectors and their operation may be installed on a case-by-case basis based on an engineering study with approval from the Traffic Engineer. These pedestrian push buttons should be placed so they are convenient to use, reachable by the disabled and not placed in the direct path for the blind as per ADA requirements. Inconvenient placement of pedestrian detectors is one of the reasons pedestrians may choose to cross the intersection illegally and unsafely.

12.3.5.6 Bicycle Detectors

The most common methods for bicycle detection include:

1. Pedestrian Push Button. With the push button, the bicyclist must stop and push the button for the controller to record the call. This may require the bicyclist to leave the roadway and proceed on the sidewalk to reach the detector.

2. Inductive Loop. The inductive loop can detect the bicycle without the bicyclist's interaction. For the greatest sensitivity of the detector, the bicyclist should be guided directly over the wire. A problem with bicycle inductive-loop detectors is that they require a significant amount of metal to be activated. Today's bicycle designs tend to use a substantial amount of non-magnetic, man-made materials to increase their strength and reduce their weight. This has substantially reduced the metal content that can be detected.

3. Video Detection System. The current video detection systems can reliably detect bicyclists. The video detection system is not dependent upon the size of the

bicycle or its occupant. Instead, the video processor compares a known background image and detection zone to the current image. If the current image shows a bicyclist within a detection zone a vehicle call is placed on the controller for the associated phase. Unlike the inductive loop, the bicyclist uses the same detection zone as a vehicle to be detected. If a separate bicycle lane does exist on an approach, then an additional detection zone may be added to detect the bicyclist.

12.3.6 Signal Mounting

Under most circumstances, the Department's preferred practice is to install the traffic signal using steel cantilever, mast-arm mounted structures. The use of span wire must be approved by the Traffic Engineer. The following presents factors on cantilever, mast-arm mounted signals that should be considered:

1. Allows for lateral placement of signal heads and placement relative to stop line for maximum conspicuity.
2. May provide post locations for supplementary signals or pedestrian signals and push buttons (MDT preferred practice).
3. Accepted as an aesthetically pleasing method for installing overhead signals in developed areas.
4. Rigid mountings provide the most positive control of signal movement in wind.
5. Costs are generally the highest.
6. On very wide approaches, it may be difficult to properly place signal heads.
7. Limited flexibility for addition of new signal heads and/or signs on existing cantilevers.

The MDT electrical detailed drawings and the MDT Standard Specifications provide the design criteria and material specifications for traffic signal structures. All cantilever structures must be designed to meet the AASHTO Standard Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals.

Overhead highway lighting may be provided, where justified. The determination for providing overhead lighting will be made on a case-by-case basis. Chapter Thirteen, the MDT electrical detailed drawings and the MDT Standard Specifications provide additional information on the design criteria and material specifications for overhead lighting.

12.3.7 Signal Display

The traffic signal display consists of many parts including the signal head, signal face, optical unit, visors, etc. The criteria set forth in the MUTCD, MDT Standard Specifications and MDT electrical detailed drawings must be followed when determining appropriate signal display arrangements and equipment. The following provides additional guidance for selecting and specifying signal display equipment:

1. Signal Housing. Signal head housings can be made from either aluminum or polycarbonate. The Department uses cast aluminum signal housings. Polycarbonate (plastic) is usually lighter and retains its color throughout its service life. However, plastic is not as strong as aluminum and tends to break when used in top- or bottom-mounted rigid installations.

2. Signal Faces. Section 12.4.1 discusses MDT's preferred signal face arrangements for use on State highways. It is MDT practice to place the signal lenses in a vertical line rather than horizontally except in rare cases where overhead obstructions may limit visibility. See the MUTCD for additional information on the arrangement of signal heads.

3. Lens Sizes. Although an 8 in (200 mm) lens size is allowed by the MUTCD, MDT's preferred practice is to use only 12 in (300 mm) lenses on State highways. MDT specifications require the use of polycarbonate traffic signal lenses that are true to color.

4. Signal Illumination. Relative to signal illumination, the designer should consider the following.

    a. Incandescent. See the MDT Standard Specifications for the Department's criteria on signal lamps.

    b. LED. One alternative to the incandescent lamp is the light-emitting diode (LED) technology. LED designs use less energy and have a longer life expectancy than incandescent lamps. The designer is referred to the ITE publication Light Emitting Diode (LED) Vehicle Traffic Signals for additional information. MDT specifies LED for red and green indications.

5. Reflectors. The reflector directs the light output from the lamp forward through the signal lens. The reflector has a parabolic shape and is designed for the lamp filament. Reflectors are available in three materials — mirrored glass, specular anodized aluminum and metalized plastic. MDT specifications require the use of Specular Alzak Aluminum reflectors.

6. Visors. MDT practice is to use a visor on all signals. These visors are typically used for two purposes — to direct the signal indication to the appropriate approaching traffic and to reduce "sun phantom." Tunnel visors provide a complete circle around the lens. Cap visors are partial visors, typically with the bottom cutaway. Open-bottom, tunnel visors reduce water and snow accumulation and do not let birds build nests within the visor. For Department installations, MDT normally uses open-bottom, tunnel visors. Visors are made of sheet aluminum.

7. Louvers. Louvers are sometimes used to direct the signal indication to a specific lane (e.g., left-turn signal for a left-turn bay). Louvers are used where several signal heads may cause confusion for the approaching driver. One example of this problem is where a left-turn signal indication is red, but the through lane indications are green. The decision on whether to use louvers depends on site conditions and will be determined on a case-by-case basis.

8. Optically Programmable Signals. Like louvers, optically programmable signals are designed to direct the signal indication to specific approach lanes and for specific distances. A major advantage is that they can be narrowly aligned so that other motorists cannot see the indication. Typical applications include closely spaced intersections and left-turn signals at skewed intersections. Optically programmable signals require rigid mountings to keep the indicator properly directed. Although the initial cost may be higher than louvers, the advantage of being less confusing often makes them cost effective. The decision on whether to use an optically programmable signal depends on site conditions and will be determined on a case-by-case basis.

9. Backplates. A signal indication may lose some of its contrast value when viewed against a bright sky or other intensive background lighting (e.g., advertising lighting). Backplates placed around the signal assembly can enhance the signal's visibility. However, backplates add weight to the signal head and can increase the effect of wind loading on the signal. It is the Department's preferred practice to use backplates with 5 in (130 mm) borders on all traffic signal heads; see the MDT Standard Specifications.

10. Pedestrian Signals. The use of pedestrian signals should conform with the criteria presented in the MUTCD, the MDT Standard Specifications and the MDT electrical detailed drawings. The Department's preferred practice for pedestrian signals is to use LEDs and the WALK and DON'T WALK symbol-display for new installations.

12.4 TRAFFIC SIGNAL DESIGN

12.4.1 Design Criteria

MDT has adopted the MUTCD criteria for the placement and design of traffic and pedestrian signals. This includes, but is not limited to, signal indications, color requirements, number of lenses per signal head, number and location of signal heads, height of signal heads, location of signal supports, etc. In addition to the MUTCD, MDT Standard Specifications, MDT electrical detailed drawings, and the references in Section 12.1.3, the following sections provide further details and information on the design of traffic signals.

12.4.1.1 Signal Displays

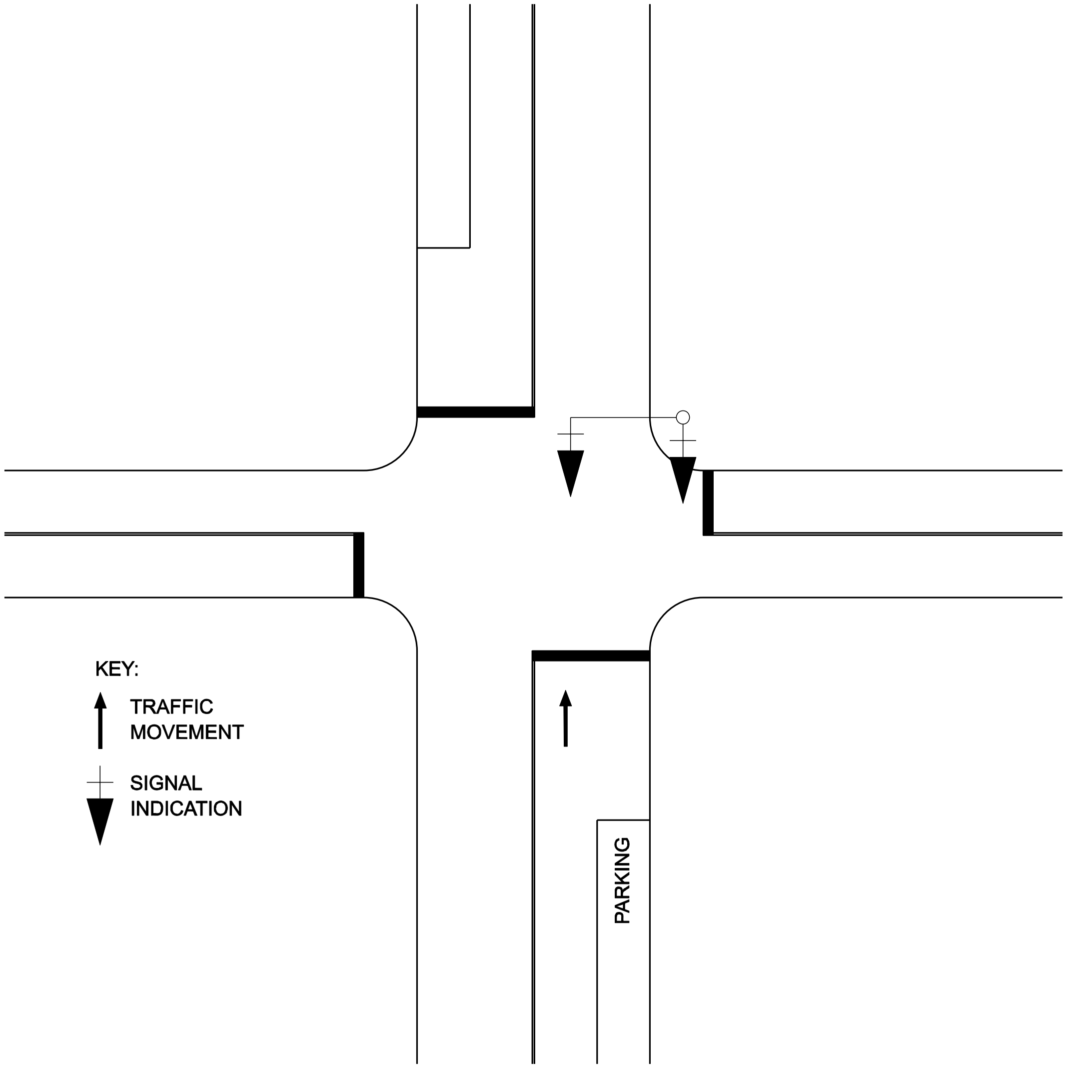
The MUTCD requires that there be at least two signal indications for each through approach to an intersection or other signalized location. A single indication is permitted for control of an exclusive turn lane, provided that this single indication is in addition to the minimum two for through movements. Figures 12.4A through 12.4D illustrate typical placement of signal heads. Supplemental signal indications (e.g., near-side signals) may be used in addition to the typical signal heads if the signal indications are marginally visible or detectable. Typical situations where supplemental indications may improve visibility include:

1. locations where there may be driver uncertainty,

2. where there are a high percentage of trucks which may block the signal indications, and/or

3. where the approach alignment affects the continuous visibility of normally positioned signal indications (e.g., left turns beyond the signal indication).

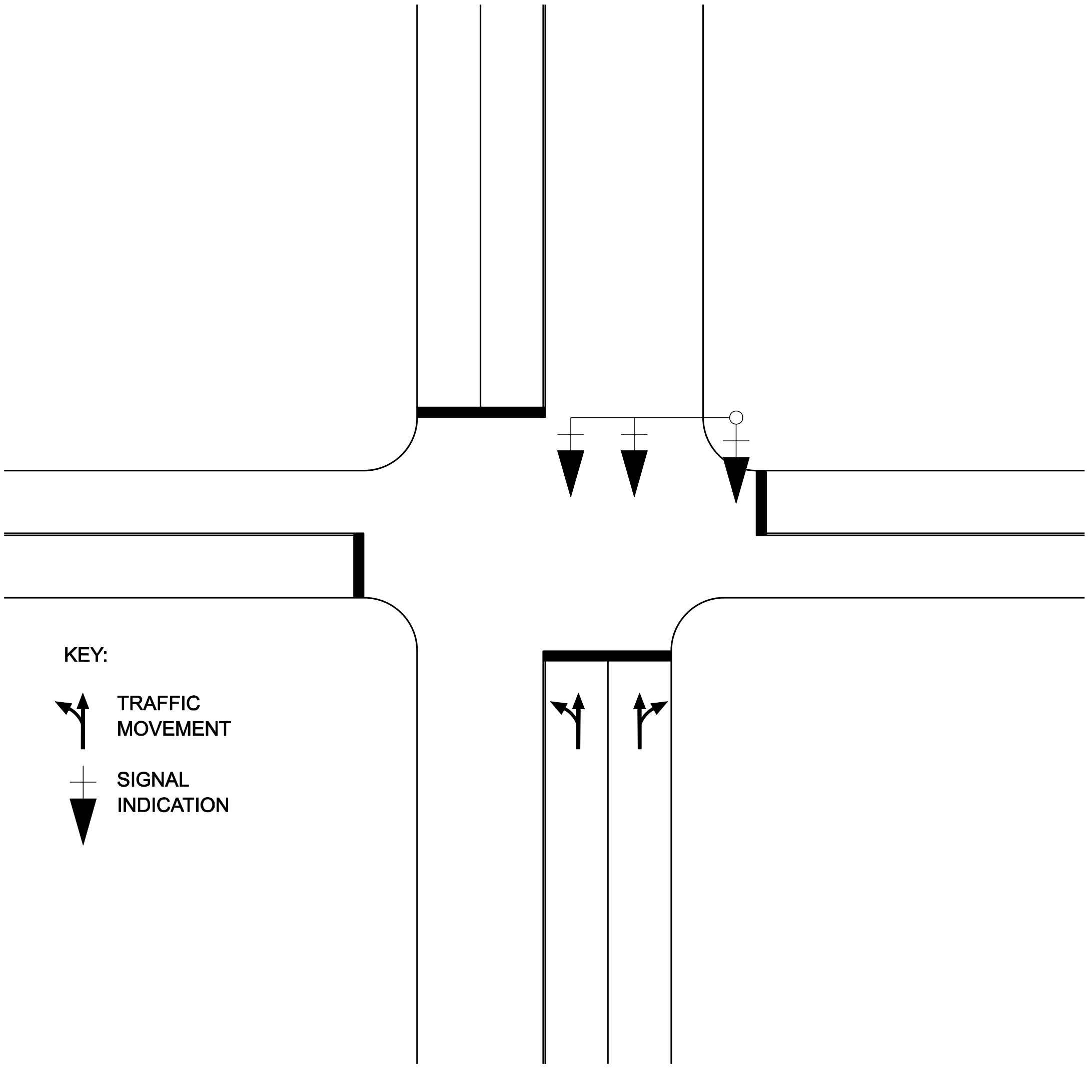
Where practical, the Department prefers the use of cantilever, mast-arm mounted signal heads that are vertically oriented in a 3- to 4-lens configuration with one signal head per lane and a supplemental signal head that is mounted on the mast-arm support. Lens size should be 12 in (300 mm) for traffic signals. New signal installations require a minimum vertical clearance of 17 ft – 6 in (5.35 m) above the pavement surface. This includes an additional 6 in (150 mm) clearance for a future pavement surface overlay. The vertical clearance for new installations should not exceed 19 ft (5.80 m). Existing



Note: Signal indications are approximately centered in lanes.

SIGNAL PLACEMENT
(Urban — No Left-Turn Lane)

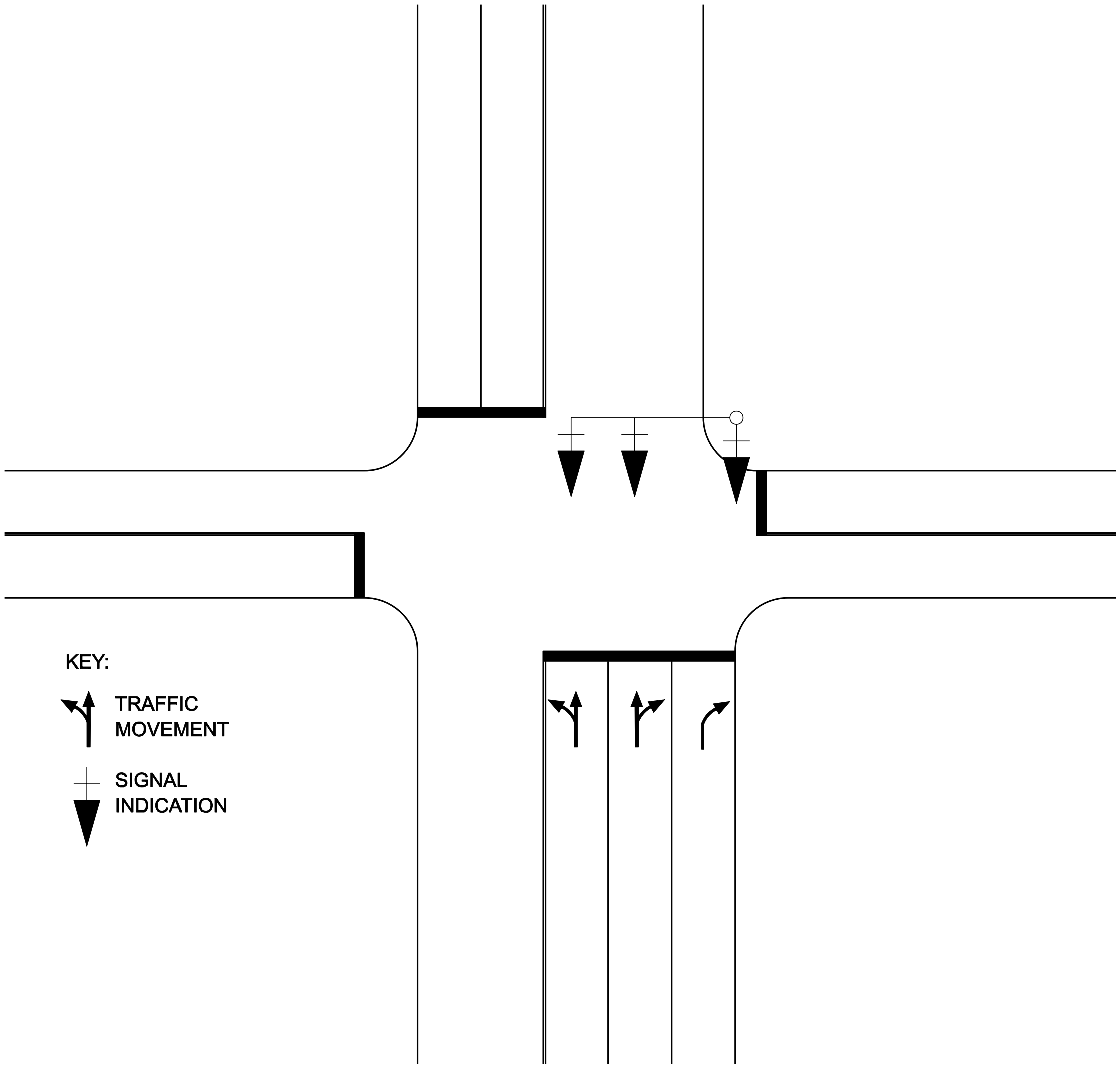
Figure 12.4A



Note: Signal indications are approximately centered in lanes.

SIGNAL PLACEMENT
(Multi-Lane Approach)

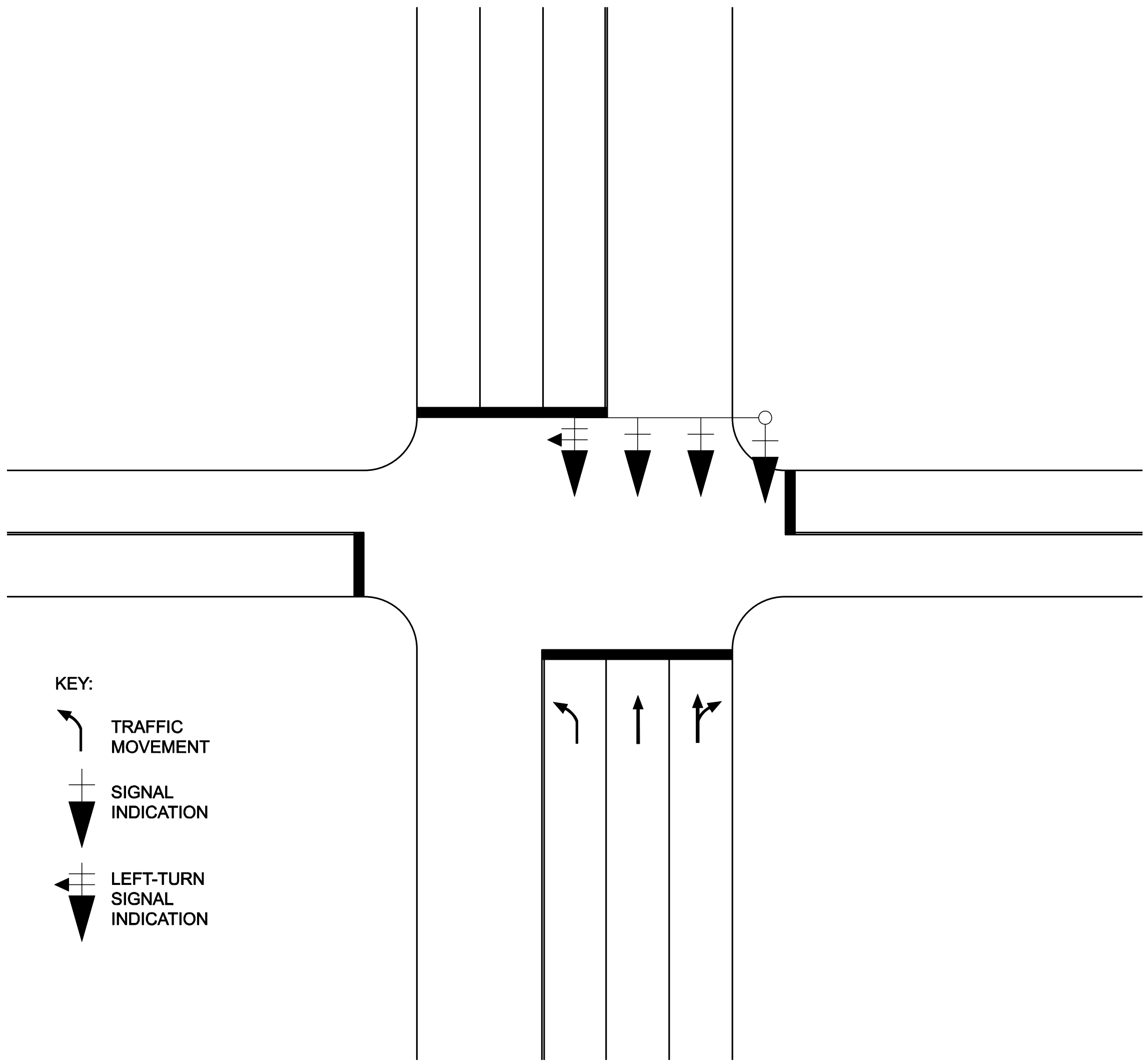
Figure 12.4B



Note: Signal indications are approximately centered in lanes.

SIGNAL PLACEMENT
(Multi-Lane Approach — Right-Turn Lane)

Figure 12.4C



Note: Signal indications are approximately centered in lanes.

SIGNAL PLACEMENT
(Multi-Lane Approach — Left-Turn Lane)

Figure 12.4D

signals may have a vertical clearance of 17 ft (5.20 m). The MDT electrical detailed drawings provide additional guidance. Figures 12.4A through 12.4D illustrate typical placement of signal heads.

12.4.1.2 Visibility Requirements

The minimum visibility for a traffic signal is defined as the distance from the stop line at which a signal should be continuously visible for various approach speeds. Figure 12.4E provides the MUTCD minimum visibility distances. If these visibility distances cannot be met, then an advance warning sign, possibly with a flashing beacon and signal interconnect, or alternative signal head location, should be used to alert the approaching drivers of the upcoming signal.

Vertically, a driver's vision is limited by the top of the vehicle's windshield. This restriction requires the signal to be located far enough beyond the stop line to be seen by the driver. The MUTCD requires a minimum distance of 40 ft (12 m) from the stop line. The Department prefers 55 ft (17 m) from the stop line. The lateral location of the indication should be in the driver's cone of vision. Research indicates that this cone of vision should be desirably within 5° on either side of the center line of the eye position (i.e., a cone of 10°). The MUTCD requires that at least one and preferably two signal faces be located within 20° on each side of the center of the approach lanes extended (i.e., a cone of 40°). As there may be confusion on where to measure the center of the approach lanes for multi-lane approaches, Figure 12.4F illustrates this requirement. The following discusses several other requirements that should be met when determining the location of signal indications:

1. Where a signal indication is meant to control a specific lane or lanes of approach, its position should make it readily visible to the drivers making the specific movement.

2. Near-side signal heads should be located as near as practical to the stop line.

3. Signal heads for any one approach should be mounted no less than 8 ft (2.5 m) apart between the center of the heads, measured perpendicular to the direction of travel.

4. At least one (and preferably all) signal head controlling through traffic should be located not less than 40 ft (12 m) (preferably 55 ft (17 m)) nor more than 180 ft (55 m) beyond the stop line; see Figure 12.4F.

US Customary									
85th Percentile Speed, mph	20	25	30	35	40	45	50	55	60
Minimum Visibility Distance, ft	175	215	270	325	390	460	540	625	715

Metric								
85th Percentile Speed, km/h	30	40	50	60	70	80	90	100
Minimum Visibility Distance, m	50	65	85	110	140	165	195	220

Note: The minimum visibility distances are based on the MUTCD.

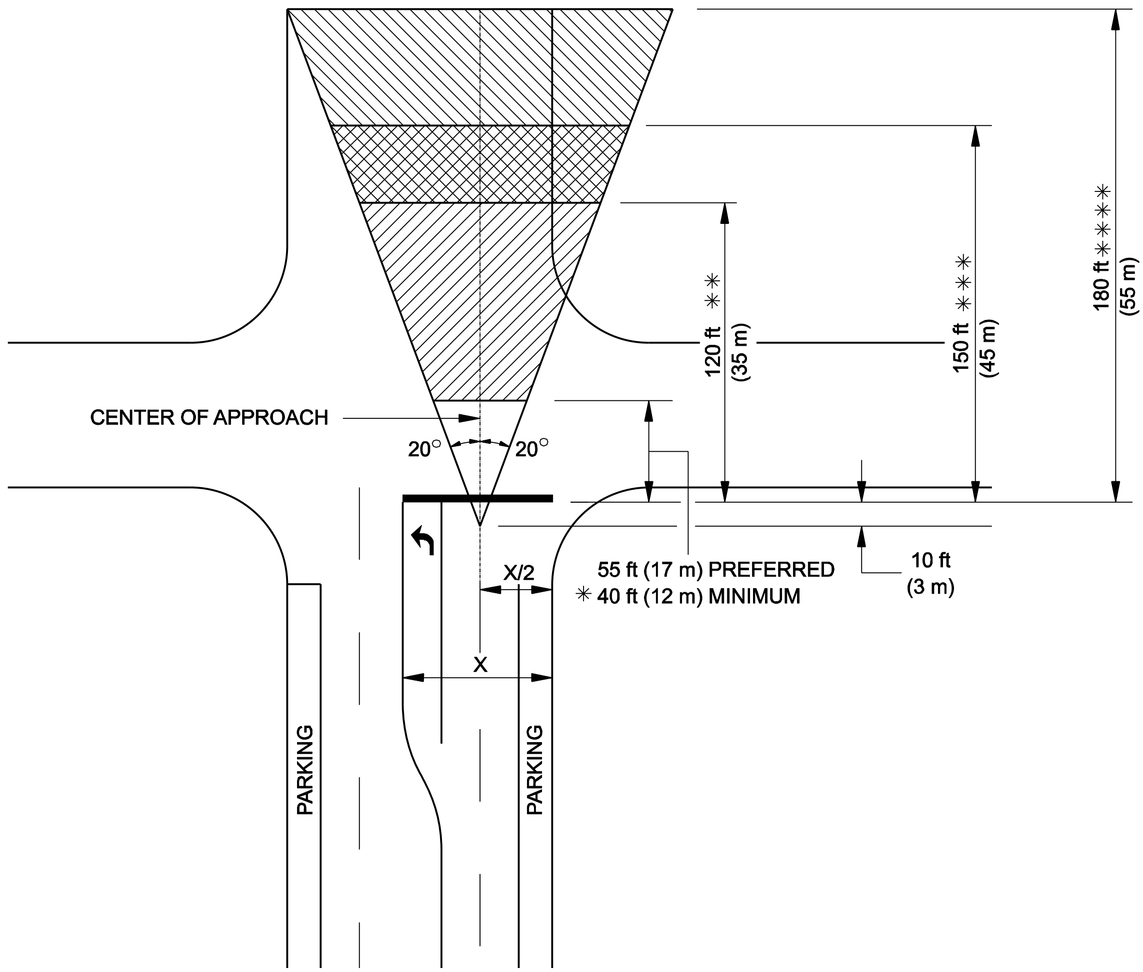
MINIMUM VISIBILITY DISTANCE

Figure 12.4E

5. Where the nearest signal head is more than 180 ft (55 m) beyond the stop line, a supplemental near-side signal head must be used; see Figure 12.4F.

12.4.2 Placement of Signal Equipment

For the most part, the designer has limited options available in determining acceptable locations for the placement of signal pedestals, signal poles, pedestrian detectors and controllers. Considering roadside safety, these elements should be placed as far back from the roadway as practical. However, due to visibility requirements, limited mast-arm lengths, limited right-of-way, restrictive geometrics or pedestrian requirements, traffic signal equipment often must be placed relatively close to the traveled way. The designer should consider the following when determining the placement of traffic signal equipment:



LOCATION OF SIGNAL HEAD(S).

8 in (200 mm) OR 12 in (300 mm) SIGNAL LENSES.

12 in (300 mm) SIGNAL LENSES, UNLESS A NEAR-SIDE SIGNAL FACE IS USED.

12 in (300 mm) SIGNAL LENSES.

✳ MINIMUM DISTANCE OF SIGNAL FACES FROM STOP LINE.

✳✳ MAXIMUM DISTANCE FROM STOP LINE FOR 8 in (200 mm) SIGNAL FACES, UNLESS A NEAR-SIDE SIGNAL FACE IS USED.

✳✳✳ MAXIMUM DISTANCE FROM STOP LINE FOR 8 in (200 mm) SIGNAL FACES WHEN NEAR-SIDE SUPPLEMENTAL SIGNAL FACE IS USED.

✳✳✳✳ MAXIMUM DISTANCE FROM STOP LINE FOR 12 in (300 mm) SIGNAL FACES, UNLESS A NEAR-SIDE SUPPLEMENTAL SIGNAL FACE IS USED.

VISION CONE

Figure 12.4F

1. Clear Zones. If practical, the placement of traffic signal equipment, if not already protected by guardrail, should meet the clear zone criteria presented in Chapter Fourteen of the MDT Road Design Manual. On low-speed facilities, signal equipment should be located beyond the back of the sidewalk, or an equivalent lateral distance if one does not exist.

2. Controller. In determining the location of the controller cabinet, the designer should consider the following:

   a. The controller cabinet should be placed in a position so that it is unlikely to be struck by errant vehicles.

   b. The controller cabinet should be located where it can be easily accessed by maintenance personnel.

   c. The controller cabinet should be located so that a technician working in the cabinet can see the signal indications in at least one direction.

   d. The controller cabinet should be located where the potential for water damage is minimized.

   e. The controller cabinet should not obstruct intersection visibility.

   f. The power service connect should be reasonably close to the controller cabinet.

3. Traffic Signal Supports. The location of the traffic signal supports (traffic signal poles, span wire poles, etc.) will be outside the clear zone or provisions must be made to ensure the support will not be struck by an errant vehicle. In urban areas where it is not practical to place the traffic signal support outside the clear zone, consider the following:

   a. Channelized Islands. Where the island is bordered by a curb and the posted speed is 45 mph or less, provide a clearance of 10 ft (3.0 m) or greater from all travel lanes. Place the standard at the back of the sidewalk, if applicable, so as not to obstruct the sight of the driver stopped at the stop line.

   b. Non-Curbed Facilities. Locate the traffic signal support a minimum of 10 ft (3.0 m) from the edge of the pavement.

   c. Curbed Facilities. Where curbs are 6 in (150 mm) or higher and the posted speed limit is 45 mph or less, locate the signal supports behind the sidewalk approximately 5 ft (1.5 m) from the face of the curb. If sidewalks are non-existent and are not planned for a later date, locate the signal supports a minimum of 2 ft (600 mm) from the face of the curb.

4. Pedestrians. If the signal pole must be located in the sidewalk, it should be placed to minimize pedestrian conflicts. In addition, the signal pole will not be placed in a manner that will restrict a disabled person's access to curb ramps. Pedestrian push buttons must be conveniently located. Chapter Eighteen of the MDT Road Design Manual provides MDT criteria for accessibility requirements for the disabled.

12.4.3 Pedestrian Signals

All pedestrian signal installations on MDT projects must meet the criteria in the MDT Standard Specifications. For local facilities, pedestrian signal installations should meet MUTCD criteria and local conditions and display the WALK and DON'T WALK standard symbol messages. The use of other displays (e.g., animated eyes, countdown) may only be used if approved by the Traffic Engineer. At locations where visually-impaired pedestrians are anticipated, supplemental audible pedestrian signals may be needed. The designer is referred to the ITE publication Audible Pedestrian Traffic Signals for the Blind for additional guidance. The use of audible signals will be determined on a case-by-case basis.

Where a signal is being considered for a mid-block crosswalk, do not provide a signal at the location if it is within 300 ft (90 m) of an existing traffic control signal, unless the proposed signal will not restrict the progressive movement of traffic. Also, mid-block crosswalks should not be signalized if they are located within 100 ft (30 m) from side streets or driveways that are controlled by STOP or YIELD signs. This will reduce potential conflicts between pedestrians and turning vehicles and improve safety.

12.4.4 Placement Marking and Signing

Cantilevers often contain regulatory and informational signs (e.g., Left-Turn Only, Street Name). The designer should consider the effect the weight of the sign and additional wind loading will have on the cantilever structure and strive to limit the number of signs on traffic signal structures. Chapter Eighteen presents additional guidance on the placement and design of signs.

Chapter Nineteen presents the criteria for the application of pavement markings at intersections. In general, pavement markings are used to supplement the traffic signal indication and lane use signs.

12.4.5 Electrical System

The electrical system consists of electrical cables or wires, connectors, conduit, pullboxes, etc.; see the MDT Standard Specifications and MDT electrical detailed drawings for details. Electrical conductors between the power supply, controller, detectors and signal poles are typically carried in conduit. The designer should consider the following when developing the traffic signal wiring plan:

1. Service Connections. Service connections from the local utility should go directly to the service disconnect and then to the controller. The length of conductor should be as short as practical. The service conductors from the service disconnect to the controller will be placed underground in separate conduits from other signal wires. Easy access to a disconnect (i.e., circuit breaker) in the controller cabinet is required to turn the power supply off when performing some maintenance activities. Utility arrangements should be initiated early in the project.

2. Electrical Cables. All electrical cables and connections must meet national, state and local electrical codes, in addition to the IMSA criteria. In general, the number of conductor cables should be kept to a minimum.

3. Cable Runs. All electrical cable runs are continuous between the controller and the terminal compartment on the side of the cantilever structure and between the terminal compartment of the cantilever structure and the signal indications.

4. Pullboxes. Pullboxes should be located adjacent to the controller cabinet, each signal pole and each detector location. Pullboxes may be combined to reduce the number of pullboxes at an intersection. The MDT electrical drawings and MDT Standard Specifications provide additional details on the design of pullboxes and wiring details.

5. Underground Conduit. Underground conduit is used to connect the controller, traffic signals and inductive loops together. Most conduits run underneath the pavement between the pullboxes and the signal poles. MDT requires maximum conduit fill to be no greater than 25% when determining the number of cables that can be contained within the conduit. Underground conduit is typically placed 2 ft (600 mm) below the ground. The Department uses both steel conduit and

Schedule 80 PVC conduit for signal installations. The MDT electrical detailed drawings and MDT Standard Specifications provide additional details on the design and placement of underground conduit.

6. Grounding. All metal poles, cantilever structures, controller cabinets, etc., must be grounded. The MDT electrical detailed drawings illustrate the correct procedures for grounding these devices. See the MDT Standard Specifications for additional criteria.

7. Loop Tagging. All loop lead-in cables should be tagged in the controller box to indicate which loop lead-in cable belongs to which inductive loop. They should be labeled according to the loop number as shown on the plan sheet.

8. Voltage Drop. A voltage drop of no more than 5% is permitted and should be checked between the service connection and the controller cabinet. Voltage drop is generally not a problem between the controller cabinet and the signal heads.

12.4.6 Phasing

The designer, in consultation with the Geometric Designer, is responsible for determining the initial phasing plan. The selected phase diagram must be included in the plans on the signal detail sheet. The following sections provide additional information on signal phasing.

12.4.6.1 Phasing Types

A signal phase is defined as the part of the cycle allotted to any vehicular or pedestrian movement. Each cycle can have two or more phases. For practicality, it is recommended that there be no more than 8 phases per cycle and desirably fewer. As the number of non-overlapping phases increases, the total vehicular delay at the intersection will increase due to the lost time of starting and clearing each phase. The designer should use the minimum number of phases practical that will accommodate the existing and anticipated traffic demands. A capacity analysis should be conducted to determine if the proposed phasing is appropriate; see Chapter Thirty. The following presents the typical applications for various phase operations:

1. Two-Phase Operation. A 2-phase operation is appropriate with a 4-way intersection that has moderate turning movements and low-pedestrian volumes.

Figure 12.4G illustrates a typical 2-phase operation. A 2-phase operation is also appropriate for the intersection of two 1-way streets.

2. Three-Phase Operation. The following describes several options where a 3-phase operation may be used:

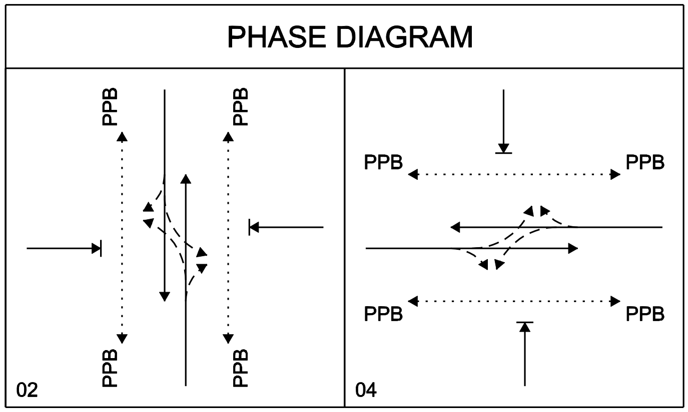
   a. Major Street With Left-Turn Lanes. A 3-phase operation should be considered where separate left-turn lanes are provided on the major street (see Figure 12.4H). A left-turn phase will typically reduce the number of left-turn crashes. Left-turning traffic from both directions should be nearly equal.

   b. T-Intersection. A 3-phase operation will typically be required if there are heavy turning volumes on the through street. The 3-phase operation allows a number of options depending on the traffic volumes and geometrics of the intersection (e.g., left- and right-turn lanes). Figures 12.4I and 12.4J illustrate a 3-phase operation at T-intersections with single-lane and multi-lane approaches.

3. Four-Phase Operation. A 4-phase operation may be used where left-turn lanes are provided on all four approaches and the left-turn volumes for each set of opposing turns is approximately equal. However, an 8-phase controller is generally more efficient for this type of operation. This phase operation may be used at the intersection of multi-lane major routes. It is most appropriate for actuated control with detection on all approaches.

4. Eight-Phase Operation. An 8-phase operation provides the maximum efficiency and minimum conflicts for high-volume intersections with heavy turning movements. Left-turn lanes should be provided on all approaches. It is appropriate for full-actuated or semi-actuated control. The 8-phase operation allows for the skipping of phases or selection of alternate phases depending upon traffic demand. Figure 12.4K illustrates a typical 8-phase operation.

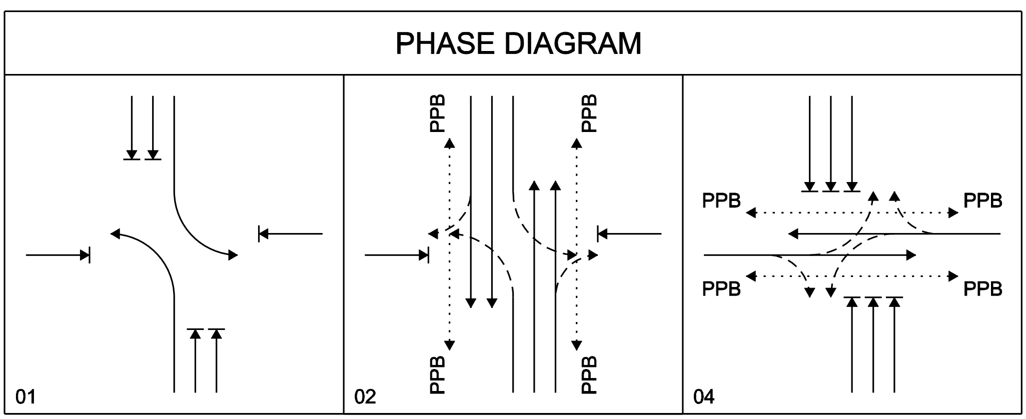
5. Other Phases. For other phase operations (e.g., 6-phase operations), one of the above phase operations can be used by eliminating the nonapplicable phase from the sequence.



NOTES:
02 PREFERENTIAL
02 FLASHES AMBER
04 FLASHES RED

TWO-PHASE OPERATION

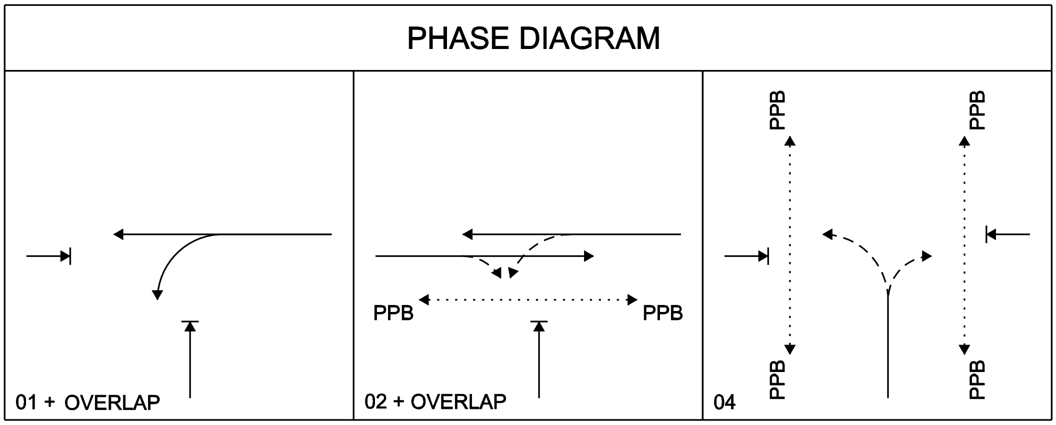
Figure 12.4G



NOTES:
02 PREFERENTIAL
02 FLASHES AMBER
04 FLASHES RED

THREE-PHASE OPERATION
(Separate Left-Turn Phase on Major Street)

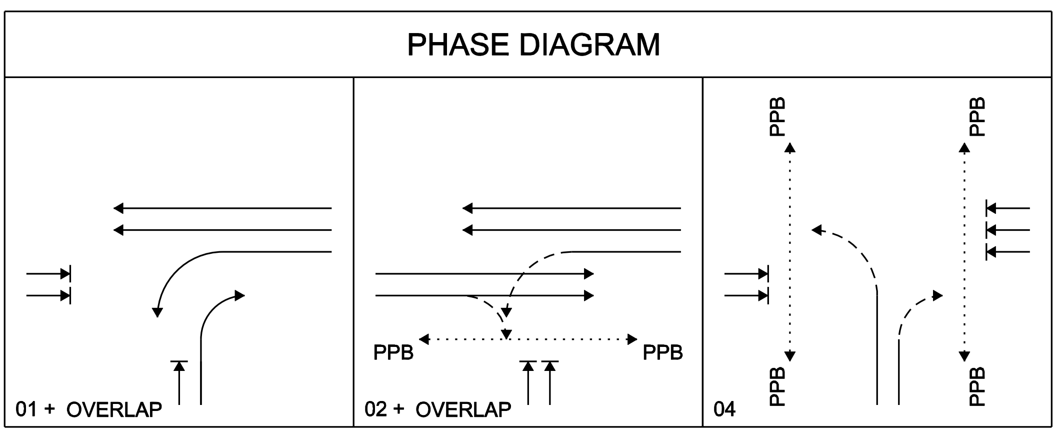
Figure 12.4H



NOTES:
02 PREFERENTIAL
02 FLASHES AMBER
04 FLASHES RED

THREE-PHASE OPERATION
T-INTERSECTION
(Single-Lane Approaches)

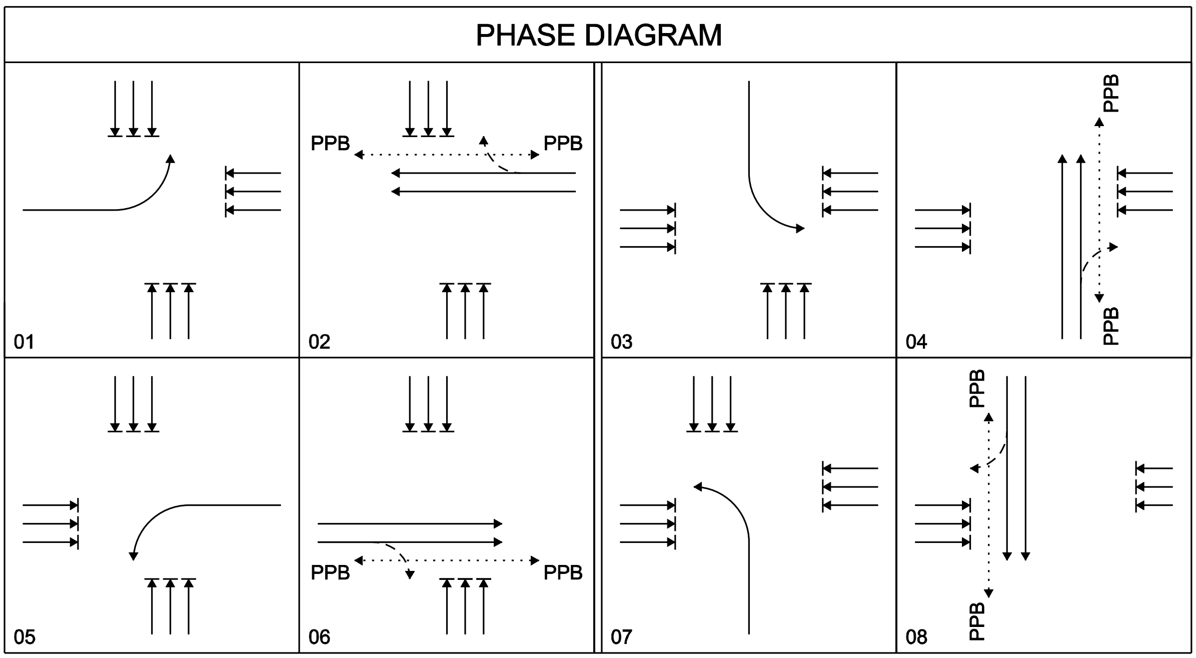
Figure 12.4I



NOTES:
02 PREFERENTIAL
02 FLASHES AMBER
04 FLASHES RED

THREE-PHASE OPERATION
T-INTERSECTION
(Multi-Lane Approaches)

Figure 12.4J



EIGHT-PHASE OPERATION
(Dual Ring)

Figure 12.4K

Figures 12.4G through 12.4K also illustrate the movements that typically should be assigned to the various numbered phases. As a general rule, on 4- and 8-phase operations, the through phases are assigned to the even-numbered phases and the left turns are assigned to the odd-numbered phases.

The controller accommodates control of each individual phase. Each phase is programmed as single-entry operation in which a single phase can be selected and timed alone. Where 4-phase controllers are involved (single-ring controllers), there are no concurrent phases timed. For controllers with 5 to 8 phases, normally there are phases that can be timed concurrently (dual-ring controllers). For example, a through movement can be timed concurrently with its accompanying left turn or its opposing through movement (i.e., Phase 1 can be timed concurrently with Phase 5 or Phase 6), but not with any other phase or vice versa. This concurrent timing is not an overlap because each phase times individually. An overlap is dependent on the phase or phases with which it is overlapped. The overlap is terminated as the parent phase or phases are terminated.

There are several computer programs available that can assist the designer in determining the appropriate phasing requirements; see Section 12.4.11. Contact the Traffic Engineering Section for more information on the latest software packages or versions used by MDT. The Department uses the Highway Capacity Software.

12.4.6.2 Left-Turn Phases

The most commonly added phases are for protected left-turns (i.e., left-turning vehicles are given a green arrow without any conflicting movements). Left-turn phases can be either a leading left, where the protected left turn precedes the opposing through movements, or a lagging left, where the left-turn phase follows the opposing through movements. The decision on when to use either a leading-left or a lagging-left turn will be determined on a case-by-case basis. In most situations, MDT's preferred practice is to use the leading left. Figure 12.4L provides a comparison for each left-turn phase alternative.

Not all signalized intersections will require a separate left-turn phase. The decision on when to provide exclusive left-turn phases is dependent upon traffic volumes, delays and crash history. This will be determined on a site-by-site basis. For intersections with exclusive left-turn lanes, the following are several guidelines that a designer may use to determine the need for a left-turn phase:

LEADING-LEFT-TURN PHASE	
ADVANTAGES	DISADVANTAGES
• Generally, increases intersection capacity of 1- or 2-lane approaches without left-turn lanes when compared with 2-phase traffic signal operation. • Minimizes conflicts between left-turn and opposing straight through vehicles by clearing the left-turn vehicles through the intersection first. • Drivers tend to react quicker than with lagging-left operations.	• Left-turning vehicles completing their movement may delay the beginning of the opposing through movement when the green is exhibited to the stopped opposing movement. • Opposing movements may make a false start in response to the movement of the vehicles given the leading green.
LAGGING-LEFT-TURN PHASE	
ADVANTAGES	**DISADVANTAGES**
• Both directions of straight through traffic start at the same time. • Approximates the normal driving behavior of vehicular operators. • Provides for vehicle/pedestrian separation as pedestrians usually cross at the beginning of straight through green. • Where pedestrian signals are used, pedestrians have cleared the intersection by the beginning of the lag-green interval. • Cuts off only the platoon stragglers from adjacent interconnected intersections.	• Left-turning vehicles can be trapped during the left-turn yellow change interval as opposing through traffic is not stopping as expected. • Creates conflicts for opposing left turns at start of lag interval because opposing left-turn drivers expect both movements to stop at the same time. • Where there is no left-turn lane, an obstruction to the through movement during the initial green interval is created.

Notes:

1. *The disadvantages inherent in lagging-left operations are such that its use is generally restricted to interconnected or pretimed operations or to a few specific situations in actuated control, such as “T” intersections.*

2. *Lagging-left turns are acceptable where both opposing through movements are stopped at the same time.*

COMPARISON OF LEFT-TURN PHASE ALTERNATIVES

Figure 12.4L

1. Capacity. A left-turn phase should be considered where the demand for left turns exceeds the left-turn capacity of the approach lane. The addition of this phase should be reviewed for its impact on the overall intersection capacity. The left-turn capacity of an approach lane is 1,200 vehicles times the percent of green time minus the opposing volume *((1,200)(G/C)-opposing volume)*, but not less than two vehicles per cycle.

2. Delay. Delay is considered excessive if a majority of left turns must be completed during the clearance interval or if left-turning vehicles are delayed for two or more complete signal cycles.

3. Miscellaneous. In addition to capacity and delay guidelines, the designer should consider intersection geometrics, total volume demand, crash history, etc.

On approaches without an exclusive left-turn lane, the decision on whether to include a left-turn phase is determined on a site-by-site basis. Where practical, opposing left-turn arrows should also be provided.

12.4.7 Pretimed Traffic Signal Timing

12.4.7.1 Guidelines for Signal Timing

For State highways, the designer is responsible for initial timing of the signal after it has been installed. This is true for both in-house and consultant-designed projects. The designer must understand the aspects of traffic signal timing so that the appropriate equipment selected will provide an efficient design. The following presents several guidelines that the designer should consider when developing the signal timing for pretimed signals:

1. Phases. The number of phases should be kept to a minimum. Each additional phase reduces the effective green time available for the movement of opposing traffic flows. In addition, there is increased lost time due to starting delays and clearance intervals. Adding concurrent phases may not reduce capacity.

2. Cycle Lengths. In general, the designer should consider the following relative to cycle lengths:

   a. Delay. For 2-phase operation, shorter cycle lengths (e.g., 60 seconds) generally produce the shortest delays.

b. Capacity. Longer cycle lengths (greater than 60 seconds) will accommodate more vehicles per hour if there is a constant demand during the entire green period on each approach. Longer cycle lengths have higher capacity because, over a given time period, there are fewer starting delays and clearance intervals.

c. Maximum. A cycle length of 120 seconds is generally targeted. However, the cycle length should be consistent with traffic volume and intensity of arrivals.

3. Green Intervals. The division of the cycle into green intervals will be approximately correct if made proportional to the critical lane volumes for the signal phases. The critical lane volumes can be quickly determined by using the Planning Application from the Highway Capacity Manual. In addition, the designer should check the green interval against the following:

   a. Pedestrians. If pedestrians will be accommodated, check each green interval to ensure that it is not less than the minimum green time required for pedestrians to cross the respective intersection approaches plus the initial walk interval time.

   b. Minimum Lengths. In general, relative to driver expectations, major movements should not have green intervals which are less than 15 seconds. An exception to this may be appropriate for special turn phases.

4. Capacity. For intersection approaches with heavy left turns, the capacity of an intersection should be checked to determine the need for a separate left-turn lane; see Section 12.4.6.2.

5. Phase Change Interval. Each phase change interval (yellow plus all red) needs to be checked to ensure that approaching vehicles can either come to a stop or clear the intersection during the change interval.

6. Coordination. Traffic signals within 0.5 mi (800 m) of each other should be coordinated together in a system. Section 12.5 further discusses signal system coordination.

7. Field Adjustments. All signal timing programs should be checked and adjusted in the field to meet the existing traffic conditions.

12.4.7.2 Cycle Determinations

In determining the appropriate cycle length and interval lengths, the designer should consider the following:

1. General. Cycle lengths should generally fall within the following ranges:

   a. 2-Phase Operations — 50 - 80 seconds.
   b. 3-Phase Operations — 60 - 100 seconds.
   c. 4-Phase Operations — 80 - 120 seconds.

2. Phase Change Interval. The yellow change interval advises drivers that their phase has expired and that they should stop or proceed through the intersection if they are too close to stop. The phase change interval length can be determined using Equation 12.4.1. The yellow change interval may be followed by a red-clearance interval (all-red phase) of sufficient duration to permit traffic to clear the intersection before conflicting traffic movements are released. For more efficient operations, start-up time for the conflicting movements may be considered when setting the length of the all-red.

$$Y + AR = t + \frac{V}{2a \pm 64g} + \frac{W + L}{V}$$ (Equation 12.4.1 – US Customary)

$$Y + AR = t + \frac{V}{2a \pm 19.6g} + \frac{W + L}{V}$$ (Equation 12.4.1 – Metric)

Where:

$Y + AR$ = sum of the yellow and any all-red, seconds(s)

t = perception/reaction time of driver, s (typically assumed to be 1 second)

V = approach speed, ft/s (m/s)

a = deceleration rate, ft/s^2 (m/s^2) (typically assumed to be 10 ft/s^2 (3 m/s^2))

W = width of intersection, ft (m) (measured from the near-side stop line to the far edge of the conflicting traffic lane along the actual vehicular path)

L = length of vehicle, ft (m) (typically assumed to be 20 ft (6.0 m))

g = approach grade, percent of grade divided by 100 (add for upgrade and subtract for downgrade)

Yellow change intervals typically are in the range of 3 to 4.5 seconds. Remaining clearance is covered by the all-red interval. A typical all-red interval is 2 seconds.

3. Green Interval. To determine the cycle division, the phase green interval is based on the results of the highway capacity analyses. An alternative method uses the proportion of the critical lane volumes for each phase. The following equations illustrate how to calculate this proportion for a 2-phase system. Signals with additional phases can be determined in a similar manner.

$$G = C - Y_a - Y_b \qquad \text{(Equation 12.4.2)}$$

$$G_a = \frac{V_a}{V_a + V_b} \times G \qquad \text{(Equation 12.4.3)}$$

$$G_b = \frac{V_b}{V_a + V_b} \times G \qquad \text{(Equation 12.4.4)}$$

Where:

G = total green time available for all phases, s

G_a & G_b = green interval in seconds calculated for streets A and B

V_a & V_b = critical lane volumes on streets A and B

Y_a & Y_b = phase change interval in seconds on streets A and B (Yellow and All Red)

C = cycle length, s

The designer also should consider the effect the pedestrian clearance interval will have on the green interval where there is an exclusive pedestrian phase, or if the pedestrian phase runs concurrently with traffic at wide intersections with short green intervals. If pedestrians walk on the green indication or on a WALK symbol-display indication, the minimum green interval should be determined using Equation 12.4.5. The walking distance is from curb to curb.

$$G = P + \frac{D}{S}$$ (Equation 12.4.5)

Where:

G = minimum green time, s
P = pedestrian start-off period, normally 4-7 seconds
D = walking distance, ft (m)
S = walking speed, ft/s (m/s) (normally 4 ft/s (1.2 m/s))

The start-off period should be at least 7 seconds in length so that pedestrians will have adequate opportunity to leave the curb or shoulder before the pedestrian clearance time begins. If pedestrian volumes and characteristics do not require a 7-second start-up period, start-up periods as short as 4 seconds may be used. Where there are fewer than 10 pedestrians per cycle, the lower limit of 4 seconds is normally adequate as a pedestrian start-off period. A walking speed of 4 ft (1.2 m) per second can be assumed for average adult pedestrians. Where significant volumes of elderly, disabled or child pedestrians are present, then a reduced walking speed should be considered. See the MUTCD for additional guidance on pedestrian signal timing.

4. Recheck. After the cycle length and interval lengths have been selected, the designer should recheck the design to ensure that sufficient capacity is available. Also, the designer may want to check several cycle lengths to ensure that the most efficient cycle length and interval lengths are used. If the initial design is inadequate, the designer will need to:

   a. select a different cycle length;

   b. select a different phasing scheme; and/or

   c. make geometric or operational changes to the intersection approaches (e.g., add left-turn lanes).

   There are several software programs available to assist in determining the most efficient design. Section 12.4.11 discusses several of these programs.

12.4.8 Actuated Controller Settings

As with pretimed controllers, the designer is responsible for the initial timing of actuated controllers after they are installed. The traffic signal designer must understand how the signal timing will affect the efficiency of the actuated signalized intersection. In addition, with actuated controllers, the traffic signal designer must understand how the signal timing will affect the placement of the inductive loops.

The design of actuated control is basically a trade-off process where the designer attempts to optimize the location of vehicular detection to provide safe operation, but yet provide controller settings that will minimize the intersection delay. The compromises that must be made among these conflicting criteria become increasingly difficult to resolve as approach speeds increase. For example, on high-speed approaches, the inductive loop should be located in advance of the dilemma zone. The dilemma zone is the decision area, on high-speed approaches, where the driver needs to decide whether to go through the intersection or stop when the yellow interval begins. Depending on the distance from the intersection and vehicular speed, the driver may be uncertain whether to stop or continue through the intersection, thus, creating the dilemma problem. Figure 12.4M further defines the dilemma zone. The following sections discuss some of the design considerations for actuated controllers.

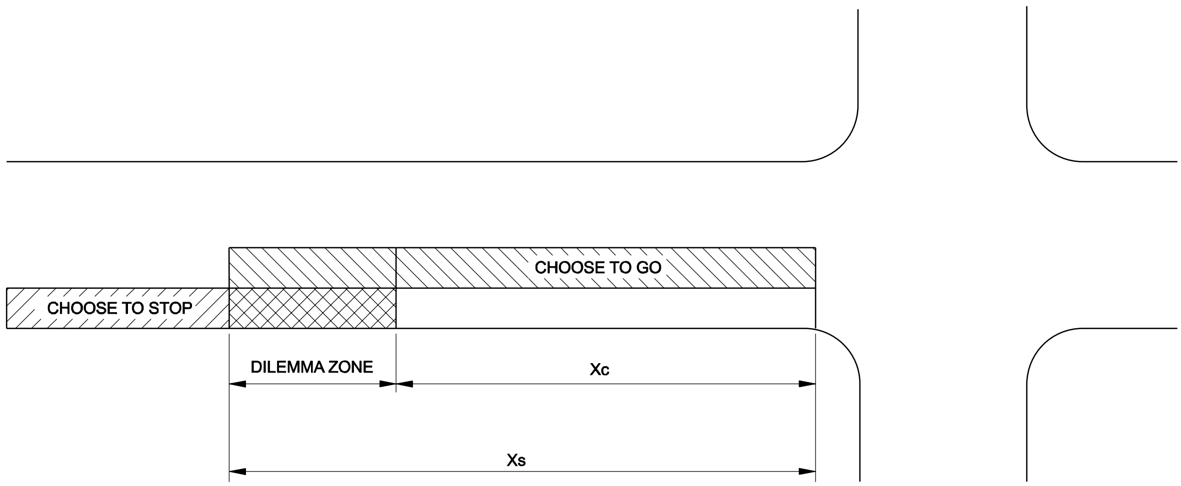
12.4.8.1 Basic-Actuated Controllers

Basic-actuated control with passage detection is limited in application to isolated intersections with fluctuating or unpredictable traffic demands and low approach speeds. Basic-actuated control includes full-actuated and semi-actuated control equipment.

Because of the small area covered by the small loop detector and its location from the stop line, this type of detection is typically used with controllers that have a locking memory feature for detector calls (i.e., the controller remembers the actuation of an inductive loop on the yellow or red, or the arrival of a vehicle that did not receive enough green time to reach the intersection).

In developing the timing criteria and loop placement for basic-actuated controllers, the designer should consider the following:

1. Minimum Assured Green (MAG). Although there is no timing adjustment labeled MAG on the controller, the designer still must calculate the MAG. The minimum green time is composed of the initial green interval plus one vehicle extension. Long minimum greens should be avoided. For quicker operations, normally, the minimum assured green should be between 10 and 20 seconds for any movement. The actual value selected should be based on the time it takes to clear all possible stored vehicles between the stop line and the loop. If the MAG is too short, the stored vehicles may be unable to reach the stop line before the signal changes. This time can be calculated using Equation 12.4.6.



Note:

1. X_C = *Maximum distance upstream of stop line from which a vehicle can clear the intersection during the yellow change interval.*

2. X_S = *Minimum distance from stop line where the vehicle can stop completely after the beginning of the yellow change interval.*

3. *At "Point A," 90% of the drivers will decide to stop at the onset of the yellow indication while 10% of the drivers will continue through the intersection.*

4. *At "Point B," 10% of the drivers will decide to stop at the onset of the yellow indication while 90% of the drivers will continue through the intersection.*

5. *For further information on dilemma zones, see FHWA Traffic Detector Handbook.*

DILEMMA ZONE

Figure 12.4M

MAG = 3.7 + 2.1 n (Equation 12.4.6)

Where:

MAG = minimum assured green, s

n = number of vehicles per lane which can be stored between the stop line and the loop

The minimum green time selected should be able to service at least two vehicles per lane. Using Equation 12.4.6, this translates into a time of approximately 8 seconds. Assuming two vehicles occupy approximately 45 ft (14 m), the inductive loop should not be placed closer than 45 ft (14 m) from the stop line. Full-actuated intersections require stop-line detection. Closer placement will not reduce the MAG.

Where pedestrians must be accommodated, a pedestrian push button should be provided. The minimum times for pedestrians, as discussed in Section 12.4.7 for pretimed signals, is also applicable to actuated systems.

2. Vehicular Extension. The vehicular extension setting fixes both the allowable gap and the passage of time at one value. The extension should be long enough so that a vehicle can travel from the inductive loop to the intersection while the signal is held in green. However, the allowable gap should be kept reasonably short to ensure quick transfer of green to the side street. Typical headways between vehicles in platoons average between 2 and 3 seconds. Therefore, the minimum vehicular extension time should be at least 3 seconds. For the maximum gap, studies have shown that drivers waiting on red find that gaps of 5 seconds or more are too long and inefficient. Therefore, the vehicular extension should be set between 3 and 5 seconds. Desirably, for quicker phase changes, shorter gaps should be used (e.g., 3 to 3.5 seconds).

3. Initial Green. The initial green setting is simply the MAG minus one vehicular extension. Typically, the initial green should be limited to a maximum of 10 seconds.

4. Detector Placement. The loop setback distance should be set equal to the time required for the typical vehicle to stop before entering the intersection. The vehicular passage time is typically used to determine this placement (e.g., 5.0 seconds). The posted speed of the approach roadway should be used to determine the appropriate setback.

5. Maximum Green Interval. This is the maximum time the green should be held for the green phase, given a detection from the side street. Typically, for light to moderate traffic volumes, the signal should "gap out" before reaching the maximum green time. However, for periods with heavy traffic volumes, the signal may rarely gap out. Therefore, a maximum green interval is set to accommodate the waiting vehicles. The maximum green interval can be determined assuming a pretimed intersection; see Section 12.4.7. It may be somewhat longer to allow for peaking.

6. Clearance Interval. The clearance interval should be determined in the same manner as for pretimed signals; see Section 12.4.7.

7. Left-Turn Lanes. Left-turn lanes should be treated like side streets with semi-actuated control. Short allowable gaps and minimum greens should be used. The design must consider vehicles that may enter the left-turn lane beyond the detector. A loop should be placed at the stop line; see Section 12.4.8.3.

8. Semi-Actuated Controllers. For minor streets with semi-actuated control, the signal is normally held on green for the major street. To ensure that the mainline is not interrupted too frequently, large minimum greens should be used on the major street. It is normally expected that the low-volume minor street will experience delay.

9. Intermediate Traffic. Where vehicles can enter the roadway between the loop and intersection (e.g., driveways, side parking) or where a vehicle may be traveling so slow that it does not clear the intersection in the calculated clearance time, the signal controller will not register their presence. A loop should be placed at the stop line to address these situations; see Section 12.4.8.3.

12.4.8.2 Advanced-Design Actuated Controllers

Advanced-design actuated controllers are usually used at isolated intersections with fluctuating or unpredictable traffic demands and high-speed approaches. An advanced-design actuated controller is one that has a variable initial interval. It can count waiting vehicles beyond the first and can extend the initial interval to meet the needs of the number of vehicles actually stored between the stop line and the inductive loop. As with basic-actuated control, the small area detection requires that the controller have a locking memory.

The timing for advanced-design actuated controllers requires a significant amount of judgment. Therefore, field adjustments are often required after the initial setup. The following discusses several considerations in the signal timing and detector placement:

1. Detector Placement. For high-speed approaches, the inductive loop should be located in advance of the dilemma zone; see Figure 12.4M. This will typically place the loop about 5 seconds from the intersection. The speed selected should be the posted speed of the approach roadway. As a rule of thumb, the Department uses 2.5 to 3.0 seconds as the length of the dilemma zone. In this instance, the typical extension interval is 3 seconds.

2. Minimum Initial. Because the advanced-actuated controller can count the number of vehicular arrivals, the minimum initial time should only be long enough to meet driver expectancy. Typically, the minimum initial interval is set at 8 to 15 seconds for through movements and 5 to 7 seconds for left turns.

3. Variable Initial. The variable initial is the upper limit to which the minimum initial can be extended. It must be long enough to clear all vehicles that have accumulated between the inductive loop and the stop line during the red. The variable initial is determined in the same manner as the minimum assured green for the basic-actuated control; see Section 12.4.8.1.

4. Number of Actuations. The number of actuations is the number of vehicles that can be accommodated during the red that will extend the initial green to the variable initial limit. This is a function of the number of approach lanes, average vehicle length and lane distribution. It should be set based on the worst-case condition (i.e., vehicles are stored back to the inductive loop).

5. Passage Time. The amount of time the green interval is displayed once vehicular demand has left the inductive loop. This is typically based on the 85th percentile speed of approach roadway.

6. Maximum Green. The maximum green should be set the same as the basic controller; see Section 12.4.8.1.

7. Allowable Gap. Density-type controllers permit a gradual reduction of the allowable gap to a preset minimum gap based on one or more cross-street traffic parameters — time waiting, cars waiting and/or density. Generally, time waiting has been found to be the most reliable and usable. As time passes after a conflicting call, the allowable gap time is gradually reduced. The appropriate minimum gap setting will depend on the number of approach lanes, the volume

of traffic and the various times of day. Fine-tuned adjustments will need to be made in the field.

8. Clearance Interval. The clearance interval should be determined in the same manner as for pretimed signals; see Section 12.4.7.

12.4.8.3 Actuated Controllers with Large Detection Areas

Large-area loops are used with a basic-actuated controller in the "non-locking" memory mode and with the initial interval and vehicular extension set at or near zero. This is referred to as the loop occupancy control (LOC). Large-area loops are used in the presence mode, which holds the vehicle call for as long as the vehicle remains over the loop. One advantage of large-area loops is that they generally reduce the number of false calls due to right-turn-on-red vehicles. With large-area loops, the length of the green time is determined by the time the area is occupied. However, a minimum green time of 8 to 15 seconds should be provided for driver expectancy. The following discusses several applications for LOC:

1. Left-Turn Lanes. An LOC arrangement is appropriate for left-turn lanes where left turns can be serviced on a permissive green or yellow change or where vehicles can enter the left-turn lane beyond the initial loop. The designer should consider the following when using the LOC for left-turns:

    a. To ensure that the driver is fully committed to making the left turn, the initial loop may need to be installed beyond the stop line to hold the call.

    b. Where motorcycles are a significant part of the vehicular stream, the vehicular extension may need to be set to 1 second so that a motorcycle will be able to hold the call as it passes from loop to loop. An alternative would be to use the extended-call detector.

2. Through Lanes (Low-Speed Approaches). On low-speed approaches, the dilemma zone protection is generally not considered a significant problem. The detection area length and controller settings are determined based on the desired allowable gap. For example, assuming a 30 mph approach speed and 3-second desired allowable gap, the LOC area is calculated to be as follows:

$$\frac{30\text{ mi}}{\text{h}} \text{ x } 3\text{ s x } \frac{5280\text{ ft}}{\text{mi}} \text{ x } \frac{\text{h}}{3600\text{ s}} = 132\text{ ft}$$

The vehicular length of 20 ft should be subtracted from the LOC, so the required detection area is 112 ft. If a typical loop layout is 45 ft long; then, for a 30 mph approach speed, the vehicular extension setting should be set at 1.5 seconds to provide the 3-second gap.

The designer should check to determine if there are pedestrian or bicyclists present; if so, the minimum green times for their crossings should be provided. Driver expectancy should also be considered.

3. Through Lanes (High-Speed Approaches). For high-speed approaches, it is generally not practical to extend the LOC beyond the dilemma zone (5 seconds of passage time back from the stop line). To cover the dilemma zone problem, an extended-call loop is placed beyond the dilemma zone. This inductive loop is used in a non-locking mode. The time extension is based on the time for the vehicle to reach the LOC area. Intermediate loops may be used to better discriminate the gaps.

   There are several concerns with using the LOC concept for high-speed approaches. Some of these concerns include the following:

   a. The allowable gap is generally higher than the normally desired 1.5 to 3 seconds. The controller's ability to detect gaps in traffic is substantially impaired. As a result, moderate traffic will routinely extend the green to the maximum setting — an undesirable condition.

   b. For high-speed approaches, LOC designs should only be used if the route is lightly traveled (e.g., 8,000 to 10,000 ADT). High-speed approaches with heavy volumes are better served with density controllers. The intersection of a high-speed arterial with a low-speed crossroad might be better served by using a density controller on the arterial and LOC for the crossroad.

12.4.9 Signal Change and Clearance Intervals

For guidance in determining yellow change and red clearance intervals not already covered in the previous sections, the designer is referred to the ITE publication Determining Vehicle Signal Change and Clearance Intervals.

12.4.10 Guidelines for Flashing Operation

During flashing operation, the major approach is typically flashed yellow and the minor approach is flashed red. Traffic signal installations will be placed in flashing operation according to the criteria presented in the MUTCD and under the following conditions:

1. Due to temporary outage of the traffic signal control equipment or to perform maintenance on the signal equipment.

2. When the requirements are not met for stop-and-go operation at special traffic signal installations (e.g., school crossing signals during non-pedestrian crossing hours, construction haul road signals, other temporary signals that are designed to operate only during specific periods of the day).

3. During off-peak hours when signalization is not justified (e.g., evenings), the intersection is typically placed in flashing operation.

12.4.11 Computer Software

There are numerous software programs available to help assist the designer in preparing traffic signal designs and timing plans. New programs, as well as updates to existing programs, are continuously being developed. Before using these programs, the designer should contact the Traffic Engineering Section to determine which software packages or versions MDT is currently using. The following programs are the most widely used for signal timing optimization:

1. Highway Capacity Software. The Highway Capacity Software (HCS) replicates the procedures described in the Highway Capacity Manual. It is a tool that greatly increases productivity and accuracy, but it should only be used in conjunction with the Highway Capacity Manual and not as a replacement for it.

2. TRANSYT-7F and SIGOP-III. The Traffic Signal Network Study Tool (TRANSYT-7F) and the Signal Timing Optimization Program (SIGOP-III) develop signal-timing plans for arterials or grid networks. The objective of both programs is to minimize stops and delays for the system as a whole, rather than maximizing arterial bandwidth.

3. Arterial Analysis Package. The Arterial Analysis Package (AAP) allows the user to easily access PASSER II and TRANSYT-7F to perform a complete analysis and design of arterial signal timing. The package contains a user-friendly forms display program so that data can be entered interactively on a microcomputer.

Through the AAP, the user can generate an input file for any of the two component programs to quickly evaluate various arterial signal-timing designs and strategies. The package also links to the "Wizard of the Helpful Intersection Control Hints" (WHICH) to facilitate detailed design and analysis of the individual intersections. The current program interfaces with TRANSYT-7F, PASSER II and WHICH.

4. PASSER II and MAXBAND. Progression Analysis and Signal System Evaluation Routine (PASSER II) and MAXBAND are known as bandwidth-optimization programs. They develop timing plans that maximize the through progression band along arterials of up to 20 intersections. Both programs work best in unsaturated traffic conditions and where turning movements onto the arterial are relatively light. PASSER II and MAXBAND can also be used to develop arterial phase sequencing for input into a stop-and-delay optimization model such as TRANSYT-7F.

5. TRAF-NETSIM. TRAF-NETSIM is a microscopic program that can be used to simulate traffic operations for arterials, isolated intersections and/or roadway networks. It can be used to determine delay, queue length, queue time, stops, stop times, travel time, speeds, congestion measures, etc. However, it does not have optimizing capabilities (i.e., the user must conduct multiple simulations to determine the "best" signal timing). It can be used with both fixed-timed and/or actuated-controlled intersections.

6. COPTRAFLO. COPTRAFLO can be used to develop time-based diagrams for arterials. It can be used to determine the optimal traffic band for both one-way or two-way arterials. The program will also allow the user to review all available solutions and will provide the offsets for the system signals based on speed and cycle lengths.

Most of these software programs can be purchased from either McTrans Center or from PC-TRANS. Many of these software programs can be purchased for either the mainframe or PC-based computer.

12.4.12 Maintenance Considerations

Depending on the existence and nature of an agreement, the District may be responsible for the maintenance of the traffic signal. Therefore, they should be consulted early in the design process for the selected signal equipment (e.g., controllers, cabinets, load switches, signal heads, lamps). The selected equipment must meet the operator's capability to adjust the signal and maintain it.

For signals on local facilities, it is the responsibility of the local municipality or county to operate and maintain the signal. The designer should review the local jurisdiction's existing traffic signal hardware and maintenance capabilities. Wherever practical, the designer should attempt to match the local jurisdiction's existing hardware. This will reduce the municipality's need for additional resources and personnel training. However, this should not necessarily limit the designer's options, because there are several consultants who can help local governments operate and maintain any traffic signal.

12.5 SIGNAL SYSTEM DESIGN

Coordination of multiple signalized intersections to form a traffic signal system is a very effective approach to improving traffic flow along a roadway or within a street grid. Coordinating the operation of two or more signalized intersections can help to ensure efficient use of the individual signal phases and can reduce the amount of vehicle-to-vehicle conflict experienced. The result is maximizing capacity potential of a street system while at the same time placing a high emphasis on minimizing crashes. The level for which these benefits can be achieved is dependent on the traffic characteristics (e.g., flow patterns), the roadway geometry, and the character of the environment adjacent to the roadway. As a general rule, signalized intersections located at a spacing of up to 0.5 mile (800 m) can be good candidates for coordination. The determination of when and how to coordinate a group of intersections must be based on a thorough site evaluation.

12.5.1 System-Timing Parameters

The basic system-timing parameters used in a coordinated system include:

1. Background Cycle. The period of time provided to serve all of the assigned intervals to their maximum allotted time within the coordination plan. In coordinated systems, the background cycle is common to all intersections in the system.

2. Split. The proportion of the cycle length among the various phases of the local controller.

3. Offset. The time relationship determined by the difference between a specific point in the local signal sequence (typically the beginning of the major street green interval) and a system-wide reference point.

4. Time of Day/Day of Week. The time-of-day/day-of-week system selects system timing plans based on a predefined schedule. The timing plan selection may be based not only on the time of day but also on the day of week.

5. Traffic Responsive. Traffic responsive systems implement timing patterns based on varying traffic conditions in or adjacent to the system. Most traffic-responsive systems select from a number of predefined patterns. These systems use a computerized library of predefined timing patterns. Real-time traffic data is collected within and/or around the system and compared in the master controller

to preset parameters. Once the associated parameters are met, a timing pattern is selected from the library and implemented.

12.5.2 Advantages and Disadvantages of Traffic Signal Systems

A primary objective of installing a traffic signal system is to develop a good coordination of traffic. Some advantages of providing good traffic coordination are as follows:

1. Traffic Flow. Traffic signal systems improve traffic flow progression and widen the green band.

2. Operational and Environmental Benefits. Traffic signal systems considerably reduce fuel consumption, pollutant emissions and vehicle operating costs.

3. Increase In Capacity. A higher level of traffic service is provided in terms of reduced travel time and reduced number of stops. Traffic flows smoothly and an improvement in capacity often results.

4. Speed Uniformity. There are less interruptions to traffic flow.

5. Crash Reduction. Fewer crashes will result because platoons of vehicles will arrive at each traffic signal at a green signal indication, thereby reducing the possibility of red signal violations and rear-end collisions. Naturally, if there are fewer occasions when a red signal indication is encountered by a majority of motorists, there is less potential for crashes that can be attributed to driver impatience or inattention, brake failure, slippery pavement conditions and other similar factors.

6. Greater Use of Arterial Streets. Through traffic will tend to remain on arterial streets rather than shifting their route over to parallel minor streets.

Disadvantages of traffic signal systems are as follows:

1. Pedestrians. Traffic signal systems can increase the delay for pedestrians waiting to cross the route under coordination.

2. Side Street Delay. The delay on the side streets at minor intersections increases because the system background cycle length is normally longer than the cycle length if the signal is not in coordination.

12.5.3 System Types

There are several different methodologies available to coordinate traffic signals. Most of these take advantage of computer technology. As new signal controllers, computers and software are developed, the design of coordinated traffic signal systems will continue to improve. These systems should match existing systems and/or be coordinated with nearby systems as practical. To maintain consistency, all consultant-design traffic signal systems must be coordinated through the Traffic Engineering Section. The following sections briefly describe several traffic signal coordination systems that are acceptable to the Department.

12.5.3.1 Interconnected Time-of-Day System

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

12.5.3.2 Time-Base-Coordinated Time-of-Day System

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

Time-base coordination allows for the inexpensive implementation of a coordinated signal system, because the need for a cable interconnect is eliminated. However, time-base systems require periodic checking by maintenance personnel, because the 60 Hz reference from the power company is sometimes inconsistent. In addition, power outages sometimes affect only portions of a system, resulting in drift between intersections that continue to operate on power company lines and those that maintain time on a battery backup.

12.5.3.3 Traffic-Responsive Arterial System

The field-located system master selects predetermined cycle lengths, splits and offsets based upon current traffic flow measurements. These selections are transmitted to coordination equipment at the local intersections.

Timing plans typically are selected based on volume (and sometimes occupancy) level thresholds on the strategically placed system loops; the higher the volumes, the longer the cycle length. Cycle splits and offsets are predetermined with the individual plans.

System sampling loops strategically located in and around the system transmit data back to the master controller. Most current systems have the capability to implement plans on a time-of-day basis as well as through the use of traffic-responsive techniques.

12.5.3.4 Closed-Loop System

Closed-loop system implies two-way communication between the intersection signal controller and the system master. In addition to the communications between the individual intersections and the system master, the system master can communicate via voice grade telephone line with a remote computer. Through the use of an external smart modem, the system master can receive and initiate telephone calls with the remote computer. The system master also serves as the communications medium between the remote computer and the intersection controller. The connection established between the system master and the remote computer allows for the interrogation of the system master, each intersection controller, the monitoring of the signal system, or the monitoring of each individual intersection. The closed-loop system is the communications technique utilized between the intersection controller, the system master, and the remote computer.

For isolated intersections, the closed-loop system is comprised of the intersection signal controller and a remote computer. The intersection signal controller uses an external smart modem to receive calls from the remote computer. The intersection signal controller cannot initiate a call to the remote computer but, once communications are established, the signal controller can be interrogated, have its parameters changed, or allow monitoring of the intersection. The two-way communications between the intersection signal controller and the remote computer form the closed-loop communications.

12.5.3.5 Distributed-Master System

The distributed-master system uses the closed-loop system to communicate between the system master, the intersection signal controller, and the remote computer. Although the operator of the remote computer can change the parameters of the system master or signal controllers, all decisions regarding the daily operation of the signal system are made by the system master.

If the system master should lose communication with one or more of the signal controllers, then the individual intersection controller operates the intersection based on the time-of-day program in the controller's memory. The loss of communications between the system master and the local controller will be transparent to the roadway user.

12.5.4 Communications Techniques

Systems other than time-base-coordinated systems require some type of communications medium to maintain synchronized operation between intersections. Two primary communications options are available. One is to employ hardwired communications through telephone lines, fiber optics or direct wiring. A second option is to utilize the through-the-air frequencies of radio communications and cellular telephone equipment. The requirements for the communications network depend on the needs of the system. Therefore, decisions on an appropriate communications technique will be made on a case-by-case basis.

12.6 FLASHING BEACONS

A flashing beacon is a traffic signal with one or more signal sections that operates in a flashing mode. It can be used as a traffic control (e.g., intersection control beacon) or advanced warning device. The designer is referred to the MDT electrical detailed drawings for typical applications of flashing beacons. The following sections present the Department's criteria for the design and application of flashing beacons on Montana roadway facilities.

12.6.1 Warning Beacons

A warning beacon is one or more sections of a standard traffic signal face with a flashing circular yellow indication in each section. It is only used to supplement the appropriate warning or regulatory sign or marker and, in general, its need is determined on a case-by-case basis. Typical applications include:

1. identifying an obstruction hazard in or immediately adjacent to the roadway;
2. as a supplement to advance warning signs (e.g., school crossings);
3. to draw attention to mid-block pedestrian crossings;
4. at signalized intersections where advanced warning is necessary (e.g., interconnected with a traffic signal controller assembly and used with a traffic signal warning sign) (This type of warning beacon is used with the first signal into a city or at isolated signals with speeds above 45 mph.); and
5. as a supplement to regulatory signs, excluding STOP, YIELD and DO NOT ENTER signs.

The condition or regulation justifying warning beacons should largely govern their location with respect to the roadway. If warning beacons have more than one signal section, they may be flashed either alternately or simultaneously. Figure 18.8G in Chapter Eighteen of Part III of the MDT Traffic Engineering Manual illustrates a typical flashing beacon and sign mounting detail.

12.6.2 Speed Limit Sign Beacons

A flashing speed limit sign beacon is intended for use with either a fixed or variable message speed limit sign.

Applications of speed limit sign beacons are on the approaches to school or senior citizen pedestrian crossings. Where applicable, the device may be used to indicate that the speed limit shown is in effect when flashing (e.g., certain time periods, special conditions).

The flashing beacon consists of one or more sections of a standard traffic signal face with a flashing circular yellow indication in each signal section. Lenses will have a visible diameter of not less than 8 in (200 mm). If two lenses are used, they will be alternately flashed and vertically aligned.

12.6.3 Intersection Control Beacons

An intersection control beacon is intended for use at an intersection where traffic or physical conditions do not justify a conventional traffic signal but where conditions (e.g., high-crash rates) indicate the possibility of a special hazard potential. The intersection control beacon consists of one or more faces, with flashing circular yellow or circular red indications in each signal face. It is installed and used only at intersection locations to control two or more directions of travel. The following provides guidance for the application of intersection control beacons:

1. Mounting. An intersection control beacon is generally suspended over the center of an intersection (e.g., span wire, mast arm); however, it may be used at other suitable locations based on engineering judgment.

2. Yellow-Red Flashing Indications. A yellow-red flashing intersection control beacon is generally designed with the flashing circular yellow indication on the major roadway (i.e., warning condition) and the flashing circular red indication on the minor roadway (i.e., stop condition). The yellow and red indications normally flash together. Do not design flashing yellow indications to face conflicting vehicular approaches.

3. Red-Red Flashing Indications. Based on engineering judgment, a red-red flashing intersection control beacon (i.e., flashing circular red indications on all approaches) may be used to supplement the primary traffic control at a multi-way stop-controlled intersection.

4. Faces. The Department specifies 12 in (300 mm) lenses and uses two faces for stop conditions and for multi-lane roadways.

5. STOP Signs. A STOP sign will be used on any approach to which a flashing red indication is shown on an intersection control beacon.

6. Supplemental Indications. Supplemental indications may be used on one or more intersection approaches to provide adequate visibility to approaching traffic.

7. Guidelines for Use at Rural Intersections. The installation of a yellow-red flashing intersection control beacon at an intersection in a rural location may be considered where one or more of the following conditions exist:

   a. Traffic Volumes. Where the minimum vehicular volume is 2500 vehicles entering the intersection during an average 24 hour period.

   b. Crashes. At rural intersections with three or more reported crashes during a 12-month period or six or more reported correctable crashes during a three-year period that have a predominance of crash types that may be corrected by cautioning and stopping traffic.

   c. Sight Distance. At locations where sight distance falls below minimum recommended criteria or where other physical or traffic conditions make it especially desirable to emphasize the need for stopping on one street and for proceeding with caution on the other.

   d. Interim Signalization Needs. At temporary intersections (e.g., haul roads, construction access points), the use of an intersection control beacon may be considered. These uses will be determined on a case-by-case basis.

12.6.4 School Crossing Sign Beacons

In general, the flashing school crossing sign beacon is used in conjunction with the SCHOOL CROSSING sign and is intended to draw the motorist's attention to an established school crosswalk. The SCHOOL CROSSING sign is placed 30 ft (9 m) in advance of the crosswalk in rural areas and 15 ft (4.5 m) in advance of the crosswalk in urban areas. Section 18.3.7 and Section 19.5.3 in Part III of the MDT Traffic Engineering Manual present additional information on the application of SCHOOL CROSSING and SCHOOL ADVANCE signs. The designer is also referred to the MDT electrical detailed drawings. If there are multiple crossings, place the beacon with the advance "SCHOOL XING" sign.

The beacon consists of two vertically-aligned sections of a standard traffic signal face (i.e., one section mounted over and one under the sign) that alternately flash yellow indications when energized. Each section consists of an 8 in (200 mm) minimum diameter lens with hood and backplate. Figure 18.8F illustrates a typical flashing school crossing sign beacon mounted on a mast arm assembly.

12.6.5 General Design of Flashing Beacons

Flashing beacons and their mountings must meet the requirements of the MDT Standard Specifications for traffic signals. The designer should also consider the following criteria on the application of flashing beacons:

1. Lens. Each lens will have a minimum nominal diameter of 8 in (200 mm) and meet the MDT specifications for yellow and red traffic signal lenses. On a case-by-case basis, depending on the application of the flashing beacon, the relative advantages of using a 12 in (300 mm) diameter lens should be considered.

2. Visors/Backplates. The use of visors and backplates with flashing beacons is encouraged and should be considered.

3. Flasher. The electrical contacts of the flasher should be equipped with filters for suppression of radio interference.

4. Flashing Mode. Beacons must flash at a rate of at least 50 but not more than 60 times per minute. The illumination period of each flash should be between one-half and two-thirds of the total cycle.

5. Time of Operation. Flashing beacons should only be operated during those hours when the warning condition or regulation exists (e.g., school openings and closings).

6. Lamp Dimming. If a flashing beacon causes excessive glare during night operation (e.g., a 150 watt lamp used in a 12 in (300 mm) flashing yellow beacon), an automatic dimming device may be necessary to reduce its brilliance.

7. Alignment/Relative Position. The edge of the signal housing is typically located a minimum of 12 in (300 mm) outside the nearest edge of the sign.

8. Location/Orientation. The obstruction or other condition justifying the use of the flashing beacon will largely govern the location of the beacon with respect to the roadway. Flashing yellow beacons, if used at intersections, will not face conflicting vehicular approaches.

9. Vertical Clearance. New installations of flashing beacons that are suspended over the roadway (e.g., span wire, mast arm) will require a minimum vertical clearance of 17 ft – 6 in (5.35 m) above the pavement surface. This includes an additional 6 in (150 mm) clearance for a future pavement surface overlay. The vertical clearance for new installations should not exceed 19 ft (5.80 m). Existing

flashing beacons suspended over the roadway may have a vertical clearance of 17 ft (5.20 m) above the pavement surface.

10. Sight Distance. When energized, flashing beacons should be clearly visible to approaching drivers for a minimum distance of 0.25 mile (400 m) under normal atmospheric conditions, unless otherwise physically obstructed.

11. Use with Traffic Signals. At signalized intersection where the use of an advance warning sign is justified to alert drivers of an approaching traffic signal, the designer should consider the relative benefits of mounting a flashing yellow beacon on the advance warning sign and interconnecting the beacon with the traffic signal controller so that the beacon is energized during the red signal indication of the warned approach.

12.7 HIGHWAY RAILROAD CROSSING SIGNALS

12.7.1 General

Where a signalized intersection is located within 200 ft (60 m) of a railroad grade crossing or where traffic frequently queues onto the tracks, the normal sequence of the traffic signals should be preempted upon approach of trains to avoid entrapment of vehicles on the crossings. The primary focus of the design of intersections where a railroad grade crossing is within 200 ft (60 m) should be to provide adequate storage area for vehicles between the track and intersection and to keep vehicles from stopping on the tracks while waiting for a green signal at the intersection. It may not be necessary to follow all of the recommendations contained in this section at crossings where train speeds are low (i.e., 10 mph (15 km/h)) or where train movements are infrequent. The railroad operations at these crossings must be confirmed in writing by the railroad before any exceptions to these guidelines will be considered.

12.7.2 Traffic Signal Design

Locations where traffic signals and railroad warning devices are interconnected should be designed differently than the typical intersection. The two signal systems must be designed to operate together to provide a safe system for both the highway users and the railroads. Communication between the traffic signal designers is critical so that everyone understands the design times and actual operations of the system. Consider the following:

1. Preemption. Ensure railroad preemption has priority over all other types of preemption in the traffic signal controller; see Section 12.3.3.5.

2. Clearance. When the signal is received from the railroad control equipment, the traffic signal controller shall terminate, using the normal clearance intervals, all phases that conflict with the track clear green phase. Any walk or pedestrian clearance intervals in effect when preemption is initiated should be immediately terminated. The pedestrian clearance may be run concurrently with the vehicular clearance interval for the cross street. However, do not extend the time needed to the cycle for the track clear green phase.

3. Signal Heads. Install four or five section signal heads to allow for a protected left-turn phase on the track approach leg of the intersection during the preemption sequence.

12.7.3 Pre-Signal

A traffic signal may be required in advance of the railroad crossing. The following criteria apply to this pre-signal:

1. Need. Place pre-signal traffic signal heads on the near side of the rails to stop vehicular traffic before the railroad crossing at all signalized intersections if the clear storage distance, measured from the stop line to a point 6 ft (1.8 m) from the rail nearest the intersection, is 50 ft (15 m) or less. At all approaches where there are high percentages of trucks, the distance should be increased to 75 ft (23 m).

2. Signal Mounting. Traffic signal heads located on the near side of the tracks should be mounted on the railroad signal structure, if available, or as close to the crossing as practical without restricting visibility of the railroad signs and signals. The use of the railroad structure requires the concurrence of the railroad company.

3. Signal Phasing. Where pre-signals are used, design the signal phase sequencing to avoid left-turning vehicles from being trapped either in the area between the intersection and the crossing, or in the intersection.

4. Timed Overlap. A timed overlap must be used to terminate the pre-signal before the far side intersection signal to clear the storage area between the tracks and the intersection with each cycle of the normal traffic signal operation. Consider vehicles that are required to make a mandatory stop (e.g., school busses, vehicles hauling hazardous materials) when determining the amount of time for the overlap to ensure they will not be forced to stop in the storage area.

5. Median. If pre-signals are needed on the near side of the tracks, a raised median may be necessary adjacent to the tracks to provide for proper placement of signals.

12.7.4 Minimum Preemption Time

The minimum preemption time at the interconnected crossings consists of the following three components:

1. Right-of-Way Maximum Time. This is the maximum worst-case time that it will take for the traffic signal to clear to a green light for the track approach. The designer should get to this green as quickly as possible by immediately

terminating any pedestrian WALK indications, abbreviating the pedestrian clearance interval, and running it concurrently with the vehicular clearance phase on the cross street. Check this abbreviated time to ensure it does not conflict with designated school routes or other conditions. This time will include a 1 second delay upon receiving the signal from the railroad to limit the number of false calls received, a 1 second minimum green for the through movement, the amber clearance and any all red time included in the timing sequence.

2. Queue Clear Time. The queue clear green time is the amount of time required to clear a vehicle that is just beyond the tracks to a point either completely through the intersection, for storage areas less that 50 ft (15 m) or to a point where the rear of the vehicle is 6 ft (1.8 m) from the near rail for longer storage areas. This time should be determined by field observations.

3. Separation Time. A separation time is added to ensure that a vehicle is not just clearing the tracks as the train enters the crossing. This is important to keep both the motorist and the engineer from taking emergency actions. This time should be set at 9 seconds.

Although the minimum preemption time from the railroad equipment is assumed to be 20 seconds as required by the Federal Railroad Administration, the designer is responsible for determining the actual preemption time.

For additional information on preempting, contact the Traffic Engineering Section.