SIGNAL SYSTEMS

Signal systems should be designed to move platoons of the volume of traffic prevailing on any section of roadway. The development of a wide "green band" to move low volumes of traffic should not restrict the flow of other traffic. Normally systems are developed to favor the flow of the arterial street traffic. Sometimes the volume of traffic entering or leaving the system from side streets may exceed the through volume on the arterial. Every effort should be made to define the origin and destination of traffic in the system and to be sure that the major flows are incorporated into the progression.

The procedure for determining the type of coordination for a new signal system or a revision to an existing signal system is a five stage process, to provide a signal system that is efficient and expandable as well as consistent with the Department's Congestion Management System.

Traffic Engineering Analysis

1. Define area to be controlled - Determine current and long-term needs, keeping in mind proposed new roadway facilities and possible future signal locations and future signal systems.

2. Determine if area to be controlled has been established as an alternate route or has the potential to be an alternate route. An alternate route is a route established by the Department to be used by motorists in the event of an incident on a freeway. The list of official alternate routes for Connecticut is maintained by the Office of Maintenance & Highway Operations - Division of Highway Operations.

3. Determine the following transportation characteristics of the area:

   a) Arterial V/C Ratio

   b) Route Characteristics
      - major commuter route
      - major commercial area
      - major recreational area

   c) Number of traffic peaks and directional flow

   d) Frequency of special events

Systems Analysis

1. Define System Parameters:

   a) Number of intersections controlled.

b) Number of timing plans using computer programs such as Synchro, Passer II, Transyt-7 or other techniques.

c) Number of System Sections - determine if the defined system should be broken down into sub-systems.

2. Define Methods of Controlling System Timing:

   a) Time of day

   b) Traffic responsive - by the use of system detectors

   c) Manual - (manual override) ability to implement special system timing plans from a remote site

Selection of Alternative Systems

1. Initial Screening:

   a) If the proposed system limits lie within an alternate route, select a closed loop system. Disregard the signal system work sheet and proceed to the approval stage.

2. Signal System Work Sheet:

   a) Fill out the signal system work sheet

   b) Select the system whose point total corresponds with the range of total points indicated below:

Type of System	Point Range
Wireless Coordination	5 - 15
Closed Loop System	16 - 24

Obtain Input from the Office of Highway Operations with the Proposed Signal System Selection

1. Upon completion of the work sheet, the originating unit shall send a Signal System Concurrence Sheet to the Office of Highway Operations indicating the Division of Traffic Engineering's preliminary recommendation regarding the type of system and requesting that office's review and comment. Accompanying the concurrence sheet should be a section of road map indicating the limits of the system and the individual signalized intersections, completed signal system work sheet, if applicable, and any other supporting data that may be appropriate.

Signal Coordination System Selection Work Sheet

Parameter	Weighted Measure			Parameter Point Total
	1	2	3	
Number of System Sections	1	2 - 4	Greater than 5	
Number of Timing Plans	3 or less	4 - 6	Greater than 6	
Alternate Route Potential	No Potential	Slight Potential	Great Potential	
Method of Controlling Signal Timing	Time of Day	Time of Day and Manual	Time of Day, Manual and Traffic Responsive	
Arterial V/C Ratio	.50 to .70	.71 to .80	> .80	
			sub total	
Parameter	Weighted Measure			
	0	3		
Route Characteristics	All Other Roadways	Major Commuter Route Major Recreational Area Major Commercial Area		
Need for Surveillance	Not Needed	Needed for Monitoring and Data Collection		
Number of Intersections	2 – 20	Greater than 20		
			sub total	
		TOTAL		

Type of System	Point Range
Wireless Coordination	5 - 15
Closed Loop System	16 – 24

Signal System Concurrence Sheet

L O C A T I O N S	TOWN: ____________________ ROUTE: ____________ DESCRIPTION: ____ ____ ____ ____ ____ ____ ____
T R A F F I C	TRAFFIC ENGINEER: ________________________________ DATE: _________________ WARRANT SHEET ATTACHED: YES: _______ NO: ________ MAP ATTACHED: YES: _______ NO: ________ SUPPORTING DATA ATTACHED: YES: _______ NO: ________ COMMENTS: ____ ____ ____ ____ TYPE OF SYSTEM RECOMMENDED: ____________________________ PRINCIPAL ENGINEER: ________________________________
O P E R A T I O N S	SYSTEMS ENGINEER: ________________________________ DATE: _________________ COMMENTS: ____ ____ ____ ____ ____ CONCUR WITH RECOMMENDED SYSTEM: YES: _______ NO: ________ PRINCIPAL ENGINEER: ________________________________
A P P R O V A L	APPROVED AS RECOMMENDED MANAGER OF TRAFFIC ENGINEERING YES: _______ NO: ________ ________________________________

Return to Unit ________

Obtain Approval of the Type of Signal System Selected

Upon the return of the Signal System Concurrence Sheet from the Office of Highway Operations and consideration of any comments, the originating unit shall forward the final recommendation for the type of signal system and all supporting information to the Manager of Traffic Engineering for approval.

Signal System Coordination Types

Closed Loop - A method of interconnecting several signalized intersections with a master. The master provides a synchronization pulse and selects timing patterns to efficiently move platoons of vehicles through the system. Timing pattern selection through the master can be accomplished manually, by time of day or through traffic responsive means. In a closed loop system local controllers communicate with the master, sending back information regarding their operation. A closed loop system allows an operator, through a central office computer, to monitor the on street master and local controller for proper operation as well as the ability to change timing functions.

Time Base Coordination - Traffic coordination based on an internal or external electronic clock rather than a physical interconnect.

Open Loop - A method of interconnecting several signalized intersections with a master. As with a closed loop system, the master provides a synchronized pulse, selects timing patterns and communicates with the local controllers regarding their operation. In an open loop system however, no communication with a central office computer is provided. This type of system is currently not used by the department.

Signal System Design

Arterial control is concerned with controlling signals along an arterial highway so as to give major consideration to progressive flow of traffic along that arterial. It is desirable to develop a time relationship between the master location and each intersection along the artery. The green should be displayed at an intersection sufficiently in advance of the arrival of a major platoon, to clear vehicles that may be stopped and to allow the platoon to continue without stopping.

It is better to arrive too early than too late. Vehicles arriving a little bit early wait a lot less time than vehicles arriving late. Early arrivals can avoid stopping by adjusting their speed. Vehicles that are a bit late are tempted to run the yellow light or increase their speed.

The timing plan of a system consists of three elements; cycle length, splits and offsets. The **splits** must be determined for each individual intersection in the system and may vary from intersection to intersection. The split is the segment of the cycle length allocated to each phase or interval that may occur (expressed in percent or seconds). In an actuated controller unit, split is the time in the cycle allocated to a phase. In a pre-timed controller unit, split is the time allocated to an interval. However, the cycle length for each signal in a system must be the same or a multiple of one another. Determination of an optimum cycle length is the key to any efficient signal system. Methods for determining optimum cycle length and phasing were discussed earlier.

When designing signals that are going to be included in a signal system, the engineer should consider progression before finalizing the phasing for the individual signalized intersections. It is important to have safe and efficient operation at each intersection but there are design options that should be considered. In lieu of quad left turn phasing for protected left turns on the artery, the designer may find that a lead-lag design would provide better progression and still provide a safe and efficient operation. Therefore, after determining the lane arrangements, signal phasing, cycle length that minimizes delay at the intersection and the number of timing plans for each intersection, the designer should perform a preliminary arterial analysis including a time space diagram.

There are many computer programs available to do this arterial review. The designer should explore cycle lengths that are compatible with the optimum intersectional cycle lengths. A review of this information should indicate if any changes to the phasing are appropriate for improved arterial operation. This process is important because signal phasing for the individual intersections can limit the ability to provide good progression through the system.

Another factor in the design of the individual intersection that may become evident during the arterial analysis is that some intersectional cycle lengths may not be compatible with the cycle length for the system during some timing plans. These intersections should be designed to have flexibility to operate full-actuated during these time periods. The same approach should be used for signals that do not have programmed flash where most of the other signals in the system flash during nighttime hours. Therefore, this process is important because it may show the need to revise signal phasing and/or the type of signalization (full vs. semi-actuated) to reduce delay and improve traffic flow along the corridor.

A system may be designed to favor directional flow during peak hours, sacrificing flow in the opposite direction to favor the heavier volume. The determination of level of service and associated **measure of effectiveness,** as discussed in Chapter 11 of The Highway Capacity Manual, may be used to evaluate different system alternatives.

Intersections that are disruptive to the progression of the platoon may be put on flash when their operation is not essential or may run free. Left turns from combination move lanes may obstruct the flow of the platoon. Corrective actions such as turn bays or special phasing should be considered. Normally it is desirable to reserve 50 % or more of the cycle length for the artery green.

Time Space Diagrams

The time relationship between intersections can be shown graphically by developing a **time-space diagram**. The time-space diagram is a technique for evaluating a proposed timing plan and determining intersection offsets, from some reference point, in an arterial system. The first step in developing a time-space diagram is to gather data, such as intersection spacing, traffic volumes (including turning movements), traffic flow variations and speed limitations. Once the field data has been obtained, the following steps are taken:

1. Prepare a graphical display of the signal system, with distance as the X axis and time as the Y axis.

2. Analyze the traffic flow variations by direction on the arterial, and determine the probable number of timing plans required.

3. For each of the timing plans to be developed, examine traffic flow conditions at the individual intersection and determine cycle length and cycle split requirements (phasing). These requirements can be determined utilizing the same methods of analysis for isolated intersections.

4. Conduct a graphical analysis to determine offsets for each of the desired timing plans as follows:

    - Plot a reference signal band for the left most signal in the system.

    - Draw a progression speed line beginning at the start of the main street green interval at the reference signal. The slope of the speed line will represent the desired progression speed (usually the posted speed or less).

    - Draw a horizontal reference line, preferably through the green interval of the reference signal.

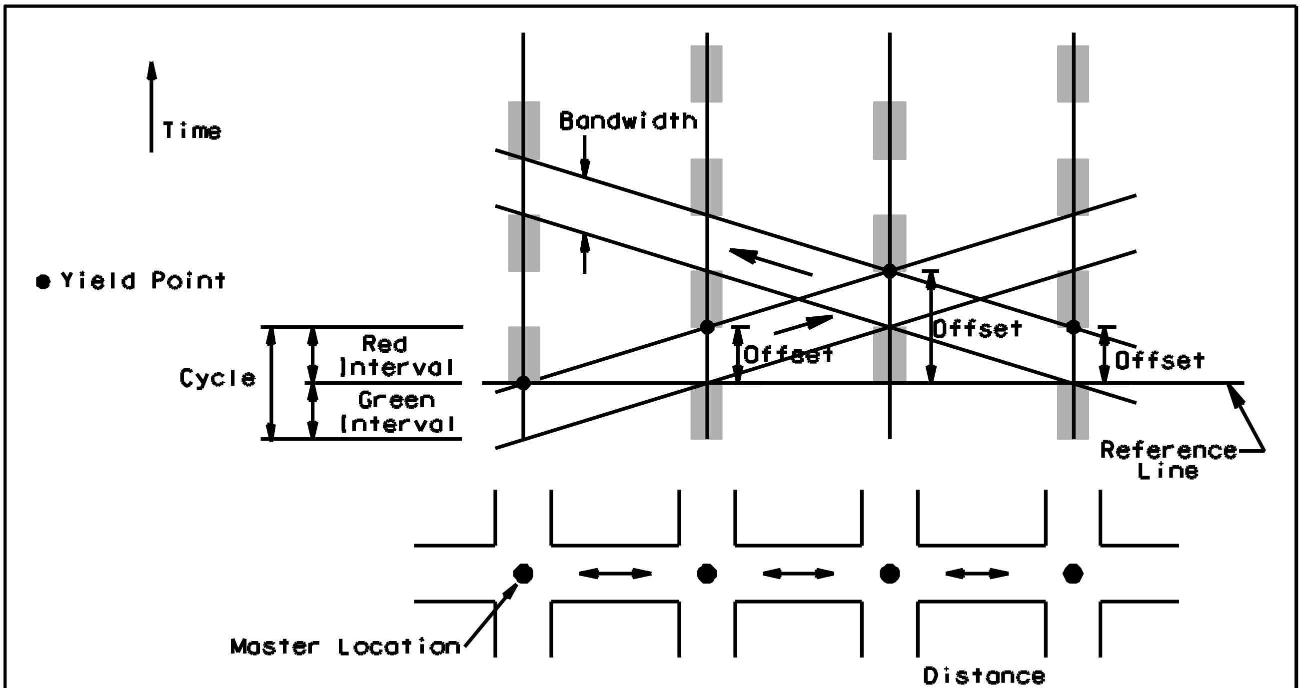
    - Center either a red or green signal interval (as required to obtain the greatest width of the through-bands) on the horizontal reference line in order to obtain an equal bandwidth for each direction of flow.

- The results of the preceding step will develop a timing plan which will provide an equal bandwidth for each direction of flow. This result can then be modified to favor one direction of flow as may be desired.

Traffic entering the arterial system from side streets may be accounted for in the time-space diagram as part of the through band or have its own separate band. The volume of traffic included in progressive flow of traffic that may enter from side streets should be determined and accounted for in the evaluation of various signal designs. All too frequently the "fine tuning" of a system in the field involves the neglect of this traffic during design.

A signal system that cannot be made to work on paper will not work in the field. Fine tuning in the field to solve progression problems is a hectic and confusing experience. Fine tuning is exactly that... fine tuning. It should consist of minor timing revisions and not wholesale changes in operation.

For signals in a coordinated system a time space relationship should be demonstrated by whatever techniques are in use at the time, including computer programs.



TIME SPACE DIAGRAM

Closed Loop Design

The following information is based on the Department's current Closed Loop software:

When signals are under external closed loop control the max settings in the local controllers are inhibited. The min green for the coordinated phase is the ped and ped clear time from the local controller. The vehicle extension, yellow time and all red time are also from the local controller. By inhibiting the max timing for phases in the local controllers, the engineer can develop a data base for the system to assign different max timings for each phase for each timing plan (splits). The designer can use the max 1 and max 2 settings for times when the signal is running under programmed free operation. Usually the designer would only run full-actuated signals under free operation. Use max 1 timings for default free operation "Central override free or coordination removed". Under free operation the system only monitors the local signal controller's operation and all the timings come from the settings on the local signal controller.

One feature that closed loop systems have is the ability to allocate **unused time** in a **sequential** operation (not quad operation of any type) from a non-artery phase to subsequent phases via the Unused Time Feature (UTF). The designer allows the time to be allocated to subsequent phases of operation for all timing plans or all unused time from the non-artery phases will be allocated to the artery phase. If this option is selected it will be shown as a technical note stating: "UNUSED TIME TO BE REALLOCATED". Utilizing this feature can be beneficial in many cases but it should be pointed out that this feature doesn't allow selection of the phase(s) to which the unused time is distributed. An example would be where you may have two sides street phases, each side street having its own phase. You may want to consider having the low volume side street phase come in first. That way if the first side street phase is skipped or gaps out, any unused time could be used by the other side street if there are sufficient calls. Since any unused time may be allocated to following phases, the designer should avoid fixed advances. If there is a fixed advance where there are different splits for each timing plan (the advance is in max recall) all the unused time from the preceding phases would be assigned to the advance phase. It should be pointed out that the designer could have a fixed advance and still allow allocation of unused time as long as the advance only has one timing instead of different splits for each timing plan (the advance would be min recall in this case).

In a closed loop system cycle lengths do not have to be increased to accommodate exclusive walk phases. If an exclusive walk phase is provided, the designer should take into account how many times an hour it is expected to be called during each timing plan. If it is expected to come in infrequently, the designer may decide to assign a zero split for the walk phase, then if the walk phase comes in, the time for the walk phase will be taken from the artery green at the start of artery green and the signal may double cycle if there isn't sufficient time in that phase to satisfy the minimum green for the artery before the yield point. This practice is not preferred because the walk takes all its time from the artery phase. It should also be noted that if the pedestrian phase comes in and causes the signal to double cycle for consecutive cycles, the signal may meet a failure condition and go to free operation. If this occurs, an engineer would have to call up the system in order to put the intersection back on line. The designer may choose to assign only part of the walk time as the split. This allows unused time to be allocated and the split for the side street phase(s) can be set lower than what the designer would call for if the walk phase did not come in. This way some of the walk time can be taken from the side street phase(s) and some from the artery.

The following is an example of how it would be done:

> Suppose you have a two-phase signal with a 60 second cycle length and the side street phase receives 20 seconds (this time includes yellow and all red). An 18 second walk phase is to be added and it is determined that 6 seconds is to be taken from the side street and 12 seconds from the artery. The designer would enter 6 seconds for the walk, 14 seconds for the side street and 40 seconds for the artery in the data base for the signal. If the walk phase comes in it gets 18 seconds from the local controller, the side street gets 14 seconds and the artery gets 28 seconds (12 seconds is taken from the start of artery green). If the walk phase is skipped the side street can receive 20 seconds of green (6 seconds assigned to the walk and the 14 seconds assigned to the side street phase).

In another example:

> Assume there is an existing three phase signal and a 17 second walk phase is to be added. The data base for the existing signal has an 8 second advance, a 32 second artery and a 20 second side street phase. In order to retain a 60 second cycle, the designer could have a 6 second advance, 32 second artery, 9 seconds for the walk phase and 13 seconds for the side street. If the walk is called, the advance and the side street would get 6 seconds and 13 seconds respectively and the artery would then receive 24 seconds (effectively 2 seconds was taken from the advance, 7 seconds from the side street and 8 seconds from the start of artery green). If the walk phase is skipped the side street could receive the 13 seconds plus all of the 9 seconds in the data base for the walk, but it would be expected that the side street phase would gap out before that occurs, so some time would then be allocated to the advance phase.

The approach used in the latter example is preferred because the cycle lengths can be shorter and it provides allocation of unused time to better suit the traffic demand. The designer can put the full time in the data base for the walk if that phase is expected to come in frequently during the period that timing plan is in effect.

The allocation of unused time (UTF) gives the designer flexibility and therefore strong consideration should be given to its use. If this function is used there should be a technical note on the plan to inform anyone reviewing the signal's operation that any unused time can be allocated to subsequent phases.

Another function that closed loop systems have is the ability to set different permissive period settings in the data base for each timing plan. This function allows the designer to increase the permissive period during off peak hours to reduce the delay to drivers on side streets and protected left turn phases. During normal daytime hours there is usually a 5% permissive period. At night when traffic volumes are low the permissive period could be increased to 20% or higher. The maximum permissive period available is equal to 1 second less than the total of the artery pedestrian clearance (usually 1 second), the artery yellow, the artery red and the minimum green of whatever phase is serviced next. Using the same 60 second cycle with 20 seconds on the side street, a 20 % permissive period would be 12 seconds. If a vehicle arrives within the first 11 seconds after the yield point, there would still be time to service the minimum side street time without affecting the system progression.

Signal System Information - for systems other than closed loop

1. The designation for various cycle lengths is pattern 1, 2, 3, etc.

2. The number of timing patterns needed is to be determined through engineering analysis and are to be indicated on the plan.

3. The controller defaults to the Max 1 time if Max 2 is not selected. Therefore, designate Max 1 as ALL OTHER TIMES. Use Max 2 for specific times such as PM peak.

4. The method used to yield the coordinated phase is Force Off. Walk and pedestrian clearance times are not needed in the artery phase.

5. New time clocks/time base coordinators accept 12-hour AM/PM programs or 24-hour military programs. Show military time on the plan. It is not necessary to designate Eastern Standard Time or Daylight Savings Time because the adjustment is made by the internal calendar. If the signal design requires a midnight setting, the time clock should be set at 23:59 (11:59 PM) not 00:00.

6. It is recommended that the total time of all phase movements be approximately 3% less than the system cycle length to eliminate the potential of double cycling.

7. On a full-actuated controller, the artery should be on Min Recall. On a semi-actuated controller, the artery should be on Max Recall.

8. When free operation is not part of the system design, list Free as "FUTURE."

9. On the time space diagram, the reference line should correspond with the beginning of the artery yellow (yield point) of the master location. The yield point at all other locations in the system will offset from there.

10. Do not use zero as an offsetting. Some manufacturers TC/TBC interpret a zero as no number having been entered. If the system design requires a zero setting, such as the master, the TC/TBC should be set at one and adjust all other offsets accordingly.

11. For locations that are full actuated, include the following technical note: Artery phase (2 and/or 6) loops to be non-actuating during coordination.

12. Flash time of day, pattern time of day and free time of day should not overlap.

13. New time base coordinated clocks have adjustable permissive periods.

Signal System Information - for closed loop systems

1. The designation for various cycle lengths is pattern 1, 2, 3, etc. Pattern 1 is for AM peak and Pattern 5 is for PM peak. Patterns 8, 9 and 10 are reserved for incident management and are not addressed during design.

2. The number of timing patterns needed is to be determined through engineering analysis and are to be indicated on the plan.

3. When coordinated, the artery maximum timer is inhibited so that only the Force Off command will release the artery phase. The artery phase will not gap out or max out. The max times shown on the plan apply only to free operation. Max 1 is always used for "All Other Times." Max 2 is used for specific time periods.

4. a. When the Call to Non-Actuated (CNA) feature is used, the controller times the walk and ped clearance intervals as the minimum green. Therefore, the artery phase must have both walk and pedestrian clearance timing. The ped clear time will be one second unless otherwise noted. Because the controller is forced out of the walk interval, the one second ped clearance is timed after the yield point and before the yellow clearance.

   b. When pre-emption is used at an intersection that has an exclusive pedestrian phase, walk and ped clear time are not programmed in the artery phase.

5. Closed loop systems have internal calendars; therefore, designs are done for military time. It is not necessary to designate Eastern Standard Time or Daylight Savings Time, the adjustment is made by the internal calendar.

6. On a full-actuated controller, the artery should be on Min Recall. On a semi-actuated controller, the artery should be on Max Recall.

7. When free operation is not part of the system design, list Free as "FUTURE."

8. System detectors should be numbered SD1, SD2, etc.

9. Offset settings should be in percent and seconds.

10. For locations that are full actuated, include a technical note to clarify that the artery detectors do not extend the artery green time during coordinated operation.

11. Flash time of day, pattern time of day and free time of day should not overlap.

12. The "Unused Time to Side Street" feature may be used if:

    a. The phase design is all sequential (sequence 1), not quad operation of any type (sequence 2. 3 or 4).

b. The intersection has two sequential vehicle phases following the artery. The lighter volume side street would be the first phase to follow the artery, then the heavier volume side street. The "unused time to side street" feature will allow any unused time from the first side street to be allocated to the second side street.

c. The intersection has an exclusive pedestrian phase:

1) A zero split may be assigned to the pedestrian phase, which may cause double cycling. However, this may be desirable if the pedestrian phase is seldom called. The designer should add a technical note "Signal may double cycle if pedestrian timing called during patterns x, x, x" for this condition.

2) A split smaller than the entire pedestrian phase may be used, which would allow any unused time to be used by the subsequent phase.

Note: This feature should be avoided if there is a non-actuated phase, such as a fixed advance. All extra time would go to that phase.

13. Add technical note: "Timings shown reflect free operation. Actual timings to be controlled/determined by ICCLU (Internal Closed Loop Local Unit)."

14. For new systems, preliminary coordination information (splits, offsets, cycle lengths, etc.) shall be indicated on the plan. For existing systems, the Highway Operations Center should be contacted to verify current coordination information.

Closed Loop Signal System Terminology

Area-wide Control	A form of signal control which treats all of the traffic signals in a city, metropolitan area, or major portion thereof as a total system.
Auto Restart	The integration of hardware logic and electrical circuitry which software programming capabilities enabling a computer system to be reactivated without operator intervention, following a power failure.
Background Cycle	The term used to identify the cycle length established by coordination unit and master control in coordinated systems.
Bandwidth	(1) The amount of green time available to a platoon of vehicles in a progressive signal system. Also referred to as through band. (2) A range of frequencies that a communications channel will carry without excessive attenuation.
Centralized System	A computer control system in which the master computer, central communication facilities, console, keyboard and display equipment are all situated at a single location. From this center, the operating staff coordinates and controls traffic signals and related traffic control functions throughout the area.
Closed-Loop Control System	A system capable of controlling some operation by implementing certain strategies, receiving inputs which permit the rapid evaluation of the effects of the control, and then taking some action which modifies the strategy on the basis of the evaluation, all without the need for the operator input.
Communication Error	Any case wherein the data received from a channel do not agree with the data transmitted.
Communication Link	The means of connecting one location to another in order to transmit and receive data.
Control Center	Consists of the room(s) that contains the computer equipment, displays and controls and houses the personnel which operate this equipment used in a computerized traffic control system.
Controller Interface Unit (CIU)	The piece of equipment inserted between the local intersection communication terminal and the intersection controller unit to translate the instructions from the computer into commands that are recognized and responded to by the controller.

Data Base	The assemblage of data constants and parameters used by the computer algorithms in the execution of the traffic control function. Normally included are timing parameters, adjustment coefficients, algorithm coefficients, limit parameters, etc.
Distributed System	A control system in which individual computers are installed in each of the major control areas of a total system, and a supervising master is used to provide interface between the individual areas and to make decision on timing patterns affecting two or more areas.
Force-Off Command (FO)	A system command that forces the termination of the right of way.
Malfunction	Any event that impairs the operation of a control system without losing the display and sequencing of signal indications to all approaching traffic.
Online	Descriptive of a system, peripheral equipment, or a process under control of the central processing unit.
Special Event Plan	A timing plan stored in memory which is activated to compensate for unusual traffic flow caused by a special event (such as football game).
Split	A division of the cycle length allocated to each of the various phases, normally expressed in percent.
Standby Mode	An operational status of a local controller assembly or system which is not under central computer control but is capable of responding to central computer control.
Surveillance	The monitoring of traffic performance and control system operation.
Timing Plan	A set of cycle length, splits and offset within a section of signals. The particular timing for each intersection may vary with time of day within the plan.
Traffic-Responsive System	A system in which a master controller (analog or digital) either selects or computes signal timing based on the real-time demands of traffic as sensed by the vehicle detectors.