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16. Abstract

   This report summarizes the recommended coordination strategies and implementation guidelines for using actuated controllers effectively in coordinated signal systems. This research has developed a reliable analytical methodology for improving the overall design and operation of actuated controllers in coordinated systems, and for generating the parameters for coordinated arterial or network operations.

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IMPLEMENTATION GUIDELINES FOR ACTUATED CONTROLLERS IN COORDINATED SYSTEMS

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IMPLEMENTATION STATEMENT

This report was sponsored by the Texas Department of Transportation under Research Study No. 0-1255, entitled "Efficient Utilization of Actuated Controllers in Coordinated Traffic Control Systems." The developed methodology will be available for analyzing signal timing at individual actuated intersections. The study will effectively assist users in selecting the proper controller/detector combinations and improving system detector locations. It will also aid users in optimizing actuated timing parameters in actuated control operation of arterial signal systems.

Successful traffic signal system implementation will maximize available resources for effective coordinated operations during undersaturated conditions, demand variations, and near saturation conditions. Three main strategies are detailed on Pages 14, 15, and 16 of this report. These strategies will allow signal systems to react quickly to anticipated volume surges, manage queues better, and recover quickly from congestion by implementing coordination strategies, such as using early return, late arrival, and platoon identification schemes. Specifically, this research could help reduce intersection delay, fuel consumption and pollution while increasing capacity.

DISCLAIMER

The contents of this report reflect only the views of the author, who is responsible for the opinions, findings, and conclusions presented herein. The contents do not necessarily reflect the official views or policies of the Texas Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

ACKNOWLEDGEMENT

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SUMMARY

This research has developed a set of reliable control strategies to allow users to improve the overall design and operation of actuated controllers in coordinated systems. The recommended analysis procedure can help users to generate the signal timing parameters for coordinated arterial or network operations. Actuated, coordinated traffic signal system implementation will maximize available resources for effective coordinated operations during undersaturated conditions, demand variations, and near saturation conditions.

This report summarizes the recommended coordination strategies and implementation guidelines for using actuated controllers effectively on coordinated signal systems.

KEY WORDS:

Traffic Signal,
Arterial Street,
Actuated Controller,
Coordination,
Arterial Progression, and
Implementation Guidelines.

I. INTRODUCTION

Many urban areas in Texas suffer from periodic traffic congestion. As major urban centers continue to experience growth in travel demands, budgetary constraints require more efficient use of existing highway facilities. Traffic growth creates the immediate need for effective traffic control that can be adapted to traffic demand variations. A serious operational problem occurs when a major arterial signal system cannot effectively move traffic along the arterials. Effective signal control and management strategies minimize traffic congestion using controllers already in the field.

Using actuated controllers minimizes vehicular stops and delay by being responsive to traffic variations. Effective use of such techniques controls widely varying volumes. The timing of actuated signal control systems involves many design elements, such as signal controller features, detector types, and detector locations. Traffic engineers must develop arterial coordination plans to assist signal control.

REPORT OBJECTIVE

This research develops a reliable analytical methodology to improve the overall design and operation of actuated controllers that can use the added flexibility of actuated control in a coordinated system, and can generate the parameters for coordinated arterial or network progression operations. The use of semi-actuated coordinated timing achieves significant operational improvements as compared to full-actuated, non-coordinated, or pretimed coordinated timing. As a result, a number of semi-actuated strategies are available to improve high-speed urban arterials with coordinated actuated signals on typical Texas arterial street systems. Many of these solutions are also applicable to other sites around the country.

This report summarizes the recommended coordination strategies and implementation guidelines for the effective usage of actuated controllers in coordinated signal systems. Operational effectiveness depends on the detector configurations and settings, controller timing, and coordination settings. The recommended signal timing and detector settings may be used as a standard design procedure for providing system adaptability using existing signal control equipment.

POTENTIAL BENEFITS

Successful traffic signal system implementation will maximize available resources for effective coordinated operations during undersaturated conditions, demand variations, and near saturation conditions. These strategies will allow signal systems to react quickly to anticipated volume surges, to manage queues better, and to recover quickly from congestion by implementing coordination settings, such as using early return, late arrival, and platoon identification schemes. These operational guidelines could also be used to take advantage of many traffic monitoring and signal system fine-tuning capabilities currently available to postpone the "possibility of over-saturation" on many state highways.

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II. AVAILABLE STRATEGIES

Three (3) basic types of control strategies are currently available for operating coordinated traffic signal systems. A recommended study approach, as shown in **Figure 1. "Traffic Signal Timing Process"** (Page 4), achieves the optimization of traffic signal timing settings using:

1. Pretimed Strategy,
2. Semi-Actuated Strategy, and
3. Fully Actuated Strategy.

The signal timing design should avoid actions that may reduce the existing intersection signal capacity. Actions such as the undesirable usage of separate turn phases and inefficient allocation of available green times may create excessively long cycles that may cause overflow of left turn bays. Cycle lengths running longer than 100 seconds usually suggest an intersection capacity problem that should be improved by adding additional turn lanes, re-striping approach lanes, and restricting parking. Floating car and side-street stopped delay studies can evaluate the before-and-after operations.

PRE-TIMED OPERATION

Pretimed controllers use fixed splits. The signal timing plans are generally developed with optimization algorithms using various data obtained from extensive traffic counts. This form of traffic control is acceptable for intersections, arterials, and networks with very minor volume variations, where the benefits of actuation do not justify the cost.

Pretimed systems can be operated efficiently using settings derived from optimization software available. The optimization objectives under such operations are to maximize the progression opportunities, to keep a good bandwidth, and to provide priority to arterial movements. Such systems operate quite well when the volumes are predictable and predominant in the through direction.

SEMI-ACTUATED OPERATION

Semi-actuated control can be used at intersections where a major street with relatively uniform flow is crossed by a minor street having traffic with relatively low operating speed and high volume fluctuations. The major phase remains green indefinitely until vehicle detectors, located on the minor approaches, are actuated. Additional actuation during the side street green can extend the minor phase to its preset maximum green. The semi-actuated controller can be applied to provide more progression through green times for better arterial coordination, thus efficiently combining the advantages of pretimed and actuated controllers.

Pretimed Conversion Strategy (Reference Page 16)

Selecting the most suitable coordination cycle length is the first important decision in signal coordination, because all intersections in the progressive system generally must operate from the same background cycle

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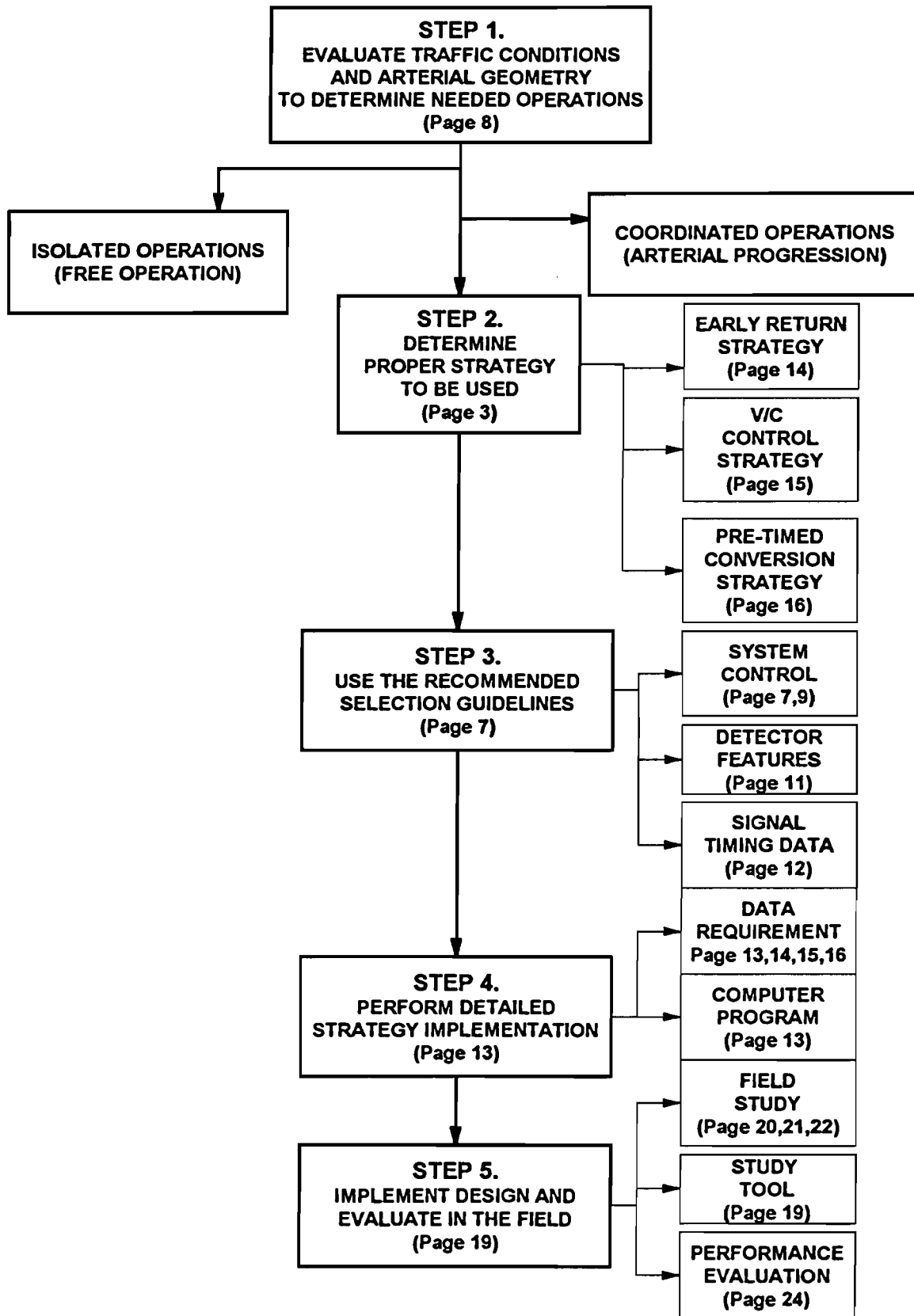
Figure 1.   Traffic Signal Timing Process.

length. Coordinated operations are needed during certain control periods, such as the AM, PM, or OFF peak periods, to accommodate progressive flow. A full-actuated controller under coordination will be operated in semi-actuated mode with proper coordinated offsets and actuated/nonactuated phasings.

Early Return Strategy (Reference Page 14)

By using the signal timing generated by pre-timed optimization packages, such as PASSER and TRANSYT-7F programs, directly to an actuated system, the extra green time left over for the side streets is wasted. This time, called "early return time" causes unused green time on the arterial outside the progression bandwidth. Offsets and splits can be devised to generate timings that effectively make use of the "early return time."

The early return timing technique attempts to use all the green splits, as suggested by pretimed optimization, and the revised coordination offsets as derived from a second optimization run using anticipated green time on the non- coordinated phases as a constraint on their maximum green times. Observing the average green split times actually being generated in the field obtains the anticipated green times. This strategy gives more green times to the non-coordinated phases in order to handle fluctuations in traffic stream.

This control strategy recognizes that PASSER II is an excellent tool for setting up progression in a fixed time system. If the signal timing plans generated by PASSER II are directly applied to an actuated system, early return typically creates unused green time on the arterial outside the progression bandwidth. To compensate for the potential early return, another PASSER II should be made to adjust the minimum splits to anticipate the amount of actual green time needed for actuated operations.

V/C Ratio Strategy (Reference Page 15)

Appropriate coordinated movements can be better selected by giving more priority to the comparatively heavy movements than the movements with lighter traffic. Features, such as the Arterial Priority Options (APO) and bandwidth weighting factors available respectively in TRANSYT-7F, MAXBAND-86 and PASSER IV programs, can provide extra priority to selected links.

The V/C Ratio or "Volume-to-Capacity Ratio" strategy keeps a target v/c ratio for some movements, and provides the main movements with the maximum possible amount of green times. Changing signal control and measuring system performance in PASSER II analysis through an iterative process can also achieve this control objective.

FULLY ACTUATED STRATEGY

Fully actuated control or "Free" operations are often used at intersections with relatively equal volumes but varying splits or having sporadic traffic distributions. Detectors are placed on all approaches to the intersections. Each phase has separate minimum green periods to provide queue dispersing time for standing vehicles. Phases can be kept on recall to give priority depending on the traffic demands on the other phases.

III. SELECTION GUIDELINES

Traffic control strategy decisions are very important to successful traffic control system operations. Evaluate existing operating conditions first. Traffic control is highly dependent upon traffic loading conditions. Different operational strategies should be devised for normal time-of-day operation, isolated operation, coordinated operation, congested operation, and late night operation. As shown in **Figure 2. "Overall Coordination Criteria"** (Page 8), a quantitative analysis methodology can be used. These criteria can be used to determine if an arterial needs to be coordinated. Alternative design considerations can be based on the actuated signal system type, study site description, and anticipated performance measures. In this way, all the geometric factors, signal phasing, detector design, and actuated settings can be carefully examined.

Figure 3. "Recommended Selection Guidelines" (Page 9) outlines a step-by-step control strategy evaluation procedure according to different time-of-day demand patterns, critical volume-to-capacity-ratio, and feasible operating conditions. In addition, the proper control strategy should address the arterial system control features, detector features, intersection timing parameters, arterial coordination schemes, and advanced management needs.

SYSTEM CONTROL FEATURES

To accommodate traffic management problems, detector inputs and advanced actuated signal controller functions should be used to improve system operations. The desirable design features of the coordinated, actuated control system include the following:

1. Use of coordinated, actuated operations.
2. Use of closed-loop system to TS2+ standards.
3. Providing all arterial coordinated action through the use of internally calculated "easy programming" features.
4. Use of coordinated phase extension on selected intersections to provide better arterial progression.
5. Providing each through phase with pedestrian signal, pedestrian detector, and MUTCD pedestrian sign.
6. Using minimum driver expectancy green times on minor movements that are not coordinated.
7. Reducing minor movement, non-coordinated phases as desired to increase coordinated phases. Use the recommended procedure to modify the PASSER II outputs.
8. Use of permitted/protected left turns as much as practicable.
9. Use of "smart detection" features on all detectors.
   a. Use "non-locking memory" for all minor/non-coordinated movements (memory off),
   b. Use of "Separate detection lane" on approaches with significant right-turn volumes,
   c. Use of "delayed calls" on permissive movements/or detector inhibit by phase status, and
   d. Use of "detector inhibit" on minor movements (queue clearance).

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ARTERIAL PROGRESSION COORDINATION CRITERIA			
NO	IMPLEMENTATION GUIDELINE	ATTRIBUTE MEASURES	
1	HIGH PERCENTAGE OF THRU TRAFFIC ON OUTBOUND LINK OF INTERSECTION (THRU TRAFFIC)	1. STATE HIGHWAY WITHOUT BYPASS	
		2. ARTERIAL STREET	
		3. LEVEL OF SERVICE EVALUATION THRESHOLD	A >= 90% (Best)
			B >= 80%
			C >= 70%
			D >= 60%
			E <= 60 (Worst)
2	HIGH PERCENTAGE OF THRU TRUCKS TRAFFIC VOLUME (TRUCK TRAFFIC)	1. TRUCK EQUIVALENT FACTOR	Lv=30, E=30/15=2.0 (light)
			Lv=42, E=39/15=2.6
			Lv=48, E=48/15=3.2 (Heavy)
3	UNIFORMLY SPACED SIGNALS THAT PROMOTE PROGRESSION AT DESIRED PROGRESSION SPEED (GOOD ARTERIAL GEOMETRY)	1. PASSER II PROGRESSION EFFICIENCY	"E" >= 25%
		2. LEVEL OF SERVICE EVALUATION THRESHOLD	A >= 35% (Best)
			B >= 25%
			C >= 15%
			D >= 5%
			E <= 5% (Worst)
4	ARTERIAL THRU VOLUMES AT MANAGEABLE LEVELS DURING PEAK HOUR PROGRESSION OPERATION (ACHIEVEABLE PROGRESSION)	1. TRAFFIC VOLUME	1. 200-450 pcphpl
		2. VOLUME-TO-CAPACITY RATIO	2. 0.4 <= v/c <= 0.9 (200) (450) c = 500 pcphpl
5	SIGNIFICANT UNI-DIRECTIONAL OR BI-DIRECTIONAL TRAFFIC PATTERN NEAR MAJOR ACTIVITY CENTERS (DIRECTIONAL PATTERN)	1. AREA LOCATION	DOWNTOWN CBD
			SUBURBAN ARTERIAL
		2. ACTIVITY CENTER	FACTORY ENTRANCE
			SHOPPING CENTER
			WORKPLACE
6	OTHER FACTORS (TO BE ADDED)	(SITE SPECIFIC CONSIDERATIONS)	

Figure 2. Overall Coordination Criteria.

EVALUATION
START

```
                     LIGHT – TRAFFIC
                       OPERATION           FULL
    ACTUATED                              ACTUATED
    EQUIPMENT          V/C < 0.4          STRATEGY

         YES

    DIRECTIONAL          NO             ISOLATED
    PEAK TRAFFIC                        OPERATION

         YES   COORDINATED
               OPERATION
                                        PRE – TIMED
      KNOWN           KNOWN             CONTROL
     PATTERNS                           STRATEGY

       UNPREDICTABLE

                               ONE – WAY
                               PROGRESSION
    CROSS STREET      YES
    SATURATED
                               OVER – SATURATION
         NO                    V/C = 1.0. 1.1, 1.2

    SEMI – ACTUATED
    CONTROL
    STRATEGY
```

ARTERIAL APPROACH   ARTERIAL APPROACH   ARTERIAL APPROACH
UNDER – SATURATION   NEAR – SATURATION   OVER – SATURATION
V/C = 0.6, 0.7, 0.8   V/C = 0.8, 0.9, 1.0   V/C = 0.9, 1.0, 1,1

                                        LOW CROSS ST.   BALANCED
CYCLE LENGTH   OFFSET   TRAFFIC   GREEN SPLIT   MAIN/CROSS ST.
IMPORTANT   IMPORTANT   IMPORTANT   TRAFFIC

PRE – TIMED   EARLY   V/C RATIO
CONVERSION   RETURN   CONTROL
STRATEGY   STRATEGY   STRATEGY
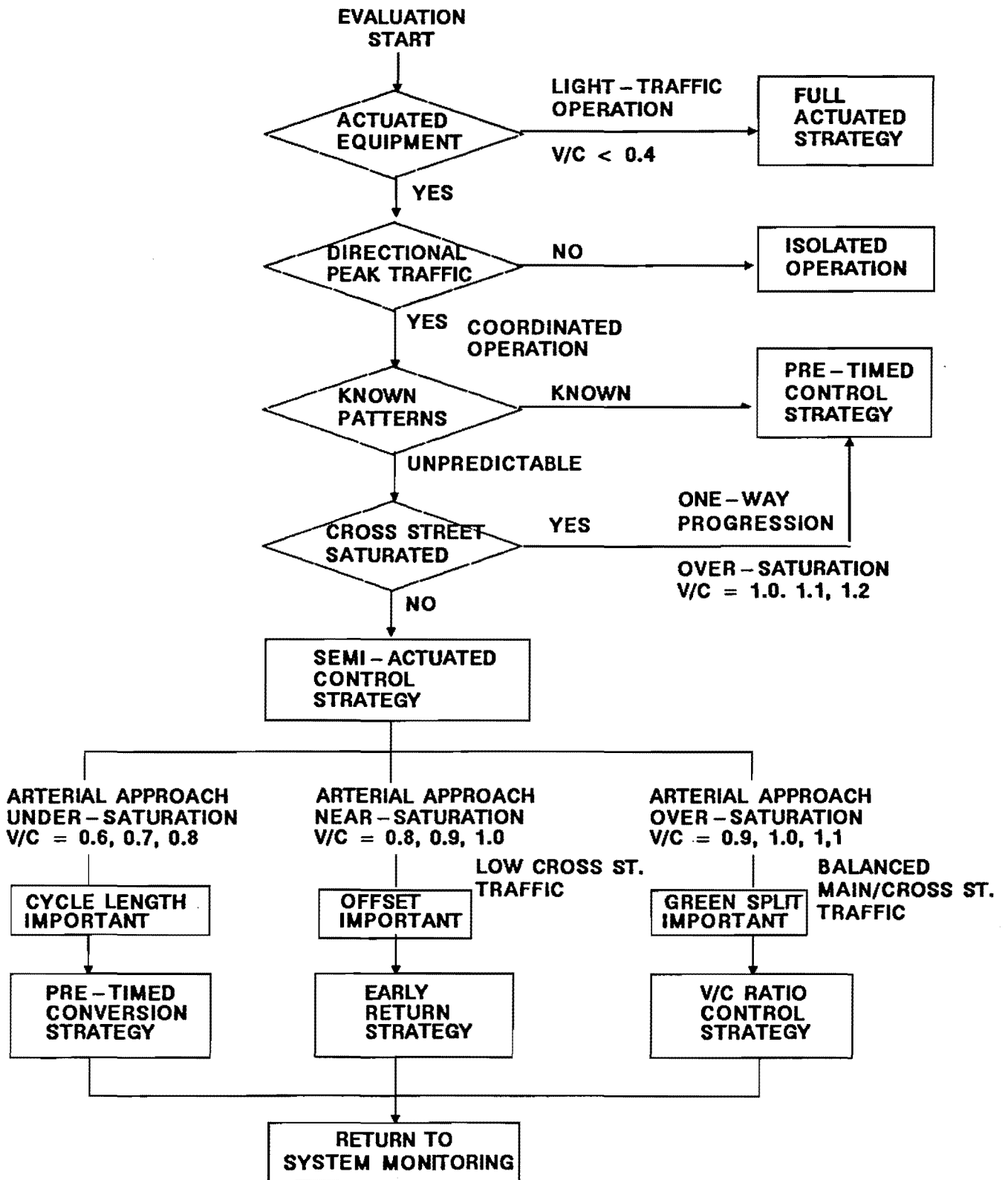
RETURN TO
SYSTEM MONITORING

Figure 3.   Recommended Selection Guidelines.

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DETECTOR FEATURES

A wide variety of vehicular detectors are currently available. However, the inductive loop detector is, by far, the most common form of detector being used. As shown in **Figure 4.** **"Typical Loop and Pedestrian Detector Applications"** (Page 11), the design configuration, size, and placement of the loop detector determine the system detection functions.

INTERSECTION TIMING PARAMETERS

Figure 5. **"Recommended Actuated Controller and Detector Settings"** (Page 12) summarizes the optimum settings recommended for both the NEMA controller and Type 170 signal controllers.

ARTERIAL COORDINATION SCHEMES

Coordination schemes are dependent on intersection signal timing parameters, background cycle length, and coordination offsets. Important intersection timing parameters should include the green splits provided for each approach, and corresponding phase sequences. The optimum system coordination setting would be made according to different background cycle length used for coordination.

The sum of all phases at each intersection would equal this background cycle length or an integral multiple of the cycle length. Each intersection cycle would be offset in time such that the vehicles leaving an intersection are processed at the next approach without having to stop. Proper timing and coordination offsets would thus provide adequate progression opportunities to the traffic through the system.

ADVANCED MANAGEMENT FEATURES

If the detection system can identify congested approaches, arterial platoons, and delayed controller actuation, three (3) advanced traffic management problems could also be addressed. These include the "Near Saturated" intersection operations, "Early Return" to main street green, and "Late Arrival" of progression platoon.

The proper linkages are made by adjusting coordination force-off schemes and phase sequences for traffic responsive operations. The existing PASSER II-90 model can make most manual signal timing adjustments and operational sensitivity evaluation.

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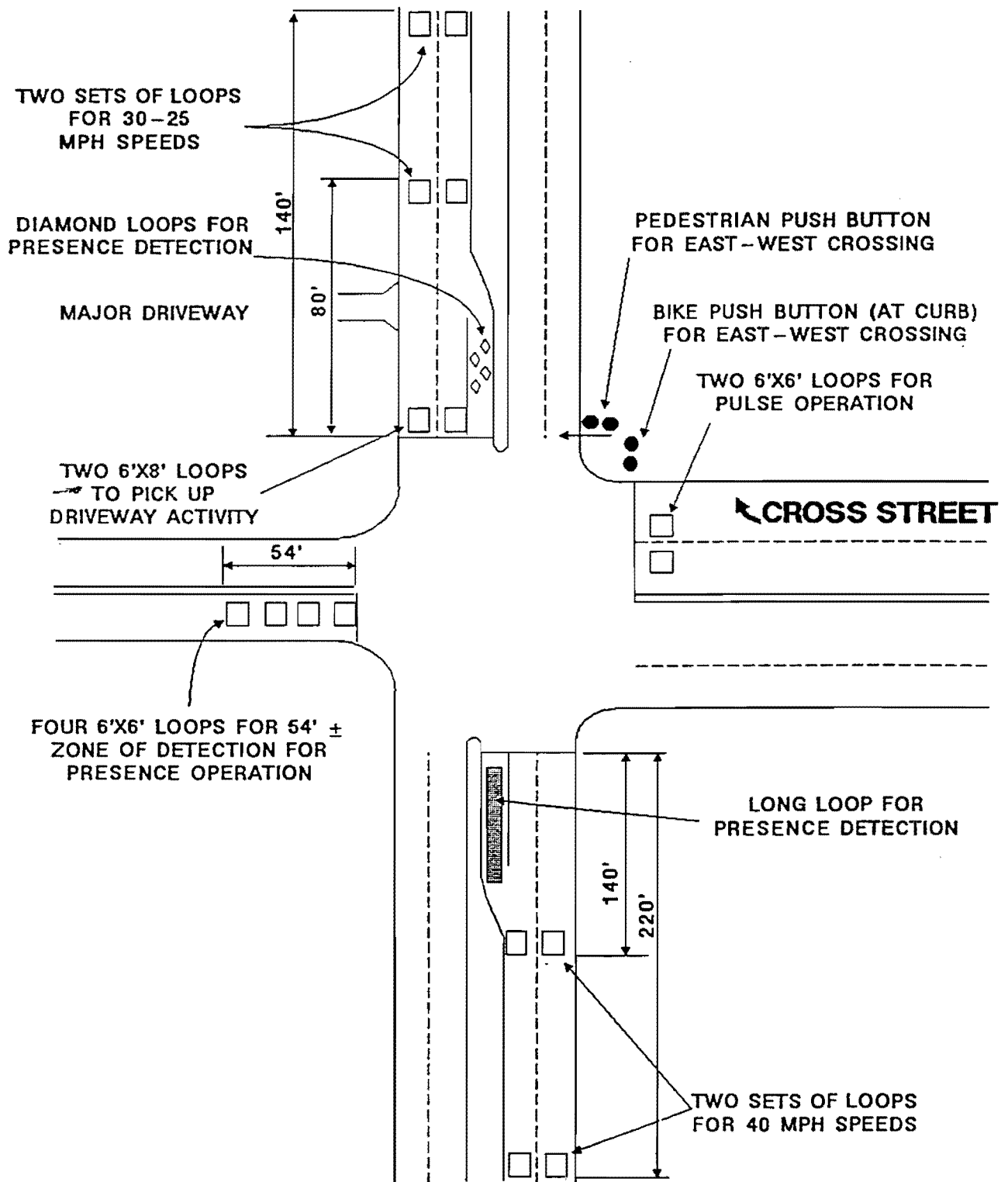# TYPICAL LOOP AND PEDESTRIAN DETECTORS
ARTERIAL STREET

TWO SETS OF LOOPS FOR 30–25 MPH SPEEDS

DIAMOND LOOPS FOR PRESENCE DETECTION

MAJOR DRIVEWAY

140'

80'

TWO 6'X8' LOOPS TO PICK UP DRIVEWAY ACTIVITY

54'

FOUR 6'X6' LOOPS FOR 54' ± ZONE OF DETECTION FOR PRESENCE OPERATION

PEDESTRIAN PUSH BUTTON FOR EAST–WEST CROSSING

BIKE PUSH BUTTON (AT CURB) FOR EAST–WEST CROSSING

TWO 6'X6' LOOPS FOR PULSE OPERATION

CROSS STREET

LONG LOOP FOR PRESENCE DETECTION

140'

220'

TWO SETS OF LOOPS FOR 40 MPH SPEEDS

Figure 4. Typical Loop and Pedestrian Detector Applications.

RECOMMENDED ACTUATED CONTROLLER AND DETECTOR SETTINGS				
NO	**ACTUATED CONTROL**	**ADVANCED FEATURES**	**AVAILABLE SYSTEM FEATURES**	
			OPERATING CONDITIONS	**RECOMMENDED SETTINGS**
1	DETECTION SYSTEM	ADVANCED DETECTION	SPEED ≥ 55 MPH	5 6' X 6' DETECTOR AT 350' BEFORE STOP BAR.
			SPEED ≥ 35 MPH	6' X 6' DETECTOR AT 210' BEFORE STOP BAR.
		LEFT TURN DETECTION	PERMITTED LEFT TURN PHASE	6' X 25' DETECTOR AT STOP BAR. 6' X 25' QUEUE DETECTOR.
			PROTECTED LEFT TURN PHASE	6' X 6' DETECTOR AT 60' UPSTREAM OF THE STOP BAR WITH 5 SECOND TIME DELAY
		SIDE STREET DETECTION	IF RIGHT TURN DETECTION REQUIRED	MULTIPLE 6' X 6' SHORT LOOPS. FRONT 25' TIME DELAYED.
2	CONTROLLER SYSTEM	MINIMUM GREEN	STOP BAR PRESENCE DETECTION	4.0 SECONDS FOR 6' X 6' DETECTOR AT THE STOP BAR
			NO STOP BAR DETECTION	10.0 SECONDS FOR 6' X 6' DETECTOR AT 210' BEFORE STOP BAR.
		VEHICLE EXTENSION	WITH RECOMMENDED DETECTOR SETBACK UNDER CONFIGURATION	2.5 SECONDS FOR 6' X 6' DETECTOR AT 210' BEFORE STOP BAR.
		TURN DELAY	LEFT TURN POCKET	5.0 SECONDS DELAY FOR 6' X 25' DETECTOR AT STOP BAR.
			RIGHT TURN DETECTION REQUIRED	1ST DETECTOR AT 25'. 10 SECONDS DELAY.
		PEDESTRIAN PROTECTION	1 CALL PER 5 CYCLE	PROVIDE PEDESTRIAN BUTTON
			36' OR HIGHER WIDTH CROSS WALK	PROVIDE PROTECTION
			PED RECALL	5.0 SECOND WALK
			PED ACTUATION	7.0 SECOND WALK
		COORDINATION GUIDELINES	ARTERIAL THROUGH PERCENTAGE ≥ 70%	COORDINATED, ACTUATED OPERATION
			VOLUME ≥ 35% OF CAPACITY	COORDINATED, ACTUATED OPERATION
			CYCLE LENGTH ≤ 150 TIMES V/C	COORDINATED, ACTUATED OPERATION
			PROGRESSION EFFICIENCY ≥ 0.13	COORDINATED, ACTUATED OPERATION

Figure 5. Recommended Actuated Controller and Detector Settings.

IV. STRATEGY IMPLEMENTATION

No operational models are readily available for optimizing control parameters explicitly for isolated or coordinated actuated operations. Three control strategies can be used to develop optimal signal timing plans through the manual approximation of timing parameters for the practical implementation of different coordinated, actuated control strategies. The following three control strategies to develop optimal signal timing plans can be used.

1. Early return strategy (Page 14),
2. V/C control strategy (Page 15), and
3. Pretimed conversion strategy (Page 16).

DATA REQUIREMENT

The basic input data required to analyze actuated signals is the same information necessary to set pretimed controller settings. These traffic signal timing input parameters include the number of phases, phase sequences, interval durations, background cycle lengths, fixed interval durations, variable interval durations, minimum phase intervals, and coordinated offsets. At the same time, signal timing analyses produced by the model represent an "equivalent pre-timed plan" developed for average traffic operating conditions during that particular control period.

Since most signalized intersections also have to accommodate pedestrian crossing timing, the provided phase link must include both vehicle and pedestrian clearance time intervals. Coordinate the proper timing of the actuated controller with signal control equipment specifications according to the user's needs. As shown in Figure 6 "Coordinated Actuated Signal Timing Parameters" (Page 17), these eight (8) elements, including yield point, force-off, green split, coordination offset, phase interval, reference offset, phase, and phase reversal, are needed for specifying the progression timing settings in addition to the basic actuated controller-detector parameters.

COMPUTER PROGRAM

The existing PASSER II-90 program can be used to improve coordination timing analysis by determining the Yield-Point and Force-Off features through the coordination offsets and phase sequences to maximize arterial progression. The model can also assist the user to determine the background cycle length and coordination offsets, or yield points, for arterial progression. However, the green splits calculated by the model are based on the average durations of phase green times for each phase movement. These green splits should be based on the heaviest input volumes and signal capacities at each intersection. The basic optimized settings should be converted into the specific settings that can be implemented on the actuated controller. However, field measurements and some estimates are still recommended to observe the traffic operating conditions and record the average phasing and interval durations most suitable for system fine-tuning needs. All other data should be recorded from controller signal timing charts so the model can simulate existing operating conditions before the correct signal timing settings can be properly implemented in the field.

EARLY RETURN STRATEGY

PASSER II is an excellent tool for setting up progression in a fixed time system. However, if the timing generated by PASSER II is directly applied to an actuated system, early return typically creates unused green time on the arterial outside the progression bandwidth. The following procedure outlines the process which tries to maximize the bandwidth by efficient use of the features of actuated equipment in a coordinated system.

1. **Target Cycle Length** Establish the target system cycle length. This will usually be the longest minimum delay cycle at any intersection in the system.

2. **Calculate Green Splits** Generate split times by using PASSER II and actual minimum split times desired. These split times are typically longer than the effective split in actuated systems due to the equipment's ability to give unused time of non-coordinated phases back to the arterial coordination. These splits can be entered as the MAX times for this cycle.

3. **Adjust Minimum Splits** To compensate for early return, make another run using PASSER II adjusting the minimum splits to anticipate the actual green time by the following procedure:

    a. Calculate the vehicles/cycle/lane for every non-coordinated approach on a vehicle per cycle basis.
    b. Assign the "anticipated green time" for each movement on the following basis and enter the values.

vehicles/cycle/lane	phase split time
1	9
2	11
3	13
4	15
5	17

    c. Make another PASSER II run.

4. **Develop Coordination Offsets** Use the offsets from the second PASSER II run to establish your progression offsets for the coordinated, actuated system.

    This "early return" procedure yields three benefits. First, it allows the user to take advantage of features of actuated equipment such as having a MAX green to handle the occasional burst of traffic. Second, it anticipates early return so that the extra green time occurs during the bandwidth, not 10 or 15 seconds prior to the arrival of the platoon. Third, by effectively utilizing the predictable green time created by early return, the green time can be used to widen the bandwidth while reducing the delay for the cross-street.

V/C CONTROL STRATEGY

This "V/C Control Strategy" design uses the existing PASSER II program to increase the coordinated phase(s) while shortening up the minor or non-coordinated phase(s) for efficient coordinated/actuated operations. The following study procedure outlines the process that can increase the length of the arterial coordinated phases, while keeping a "Target V/C Ratio," say 85% to 90%, in order to achieve a certain level of the intersection movement saturation condition, for the non-coordinated phase.

1. **Check Critical Phase** The major phases for the heavy traffic movement on both the arterial and cross street are those movements that have the highest volume-to- capacity ratios as calculated by PASSER II.

2. **V/C Calculation** The user should, at first, calculate the sum (S) of all the ratio of the volume-capacity ratio (Ri) between each phase and the maximum ratio from PASSER II output.

    S = SUM ((1 - Ri) x (PASSER II Phase Length - Lost Time per phase))

    This sum (S) represents the total amount of possible green time reduction combined from all non-coordinated critical phases while keeping the reasonable amount of green times at all other movements.

3. **Add Arterial Green** Add the possible reduction in the non-coordinated phases to the minimum phase time at the targeted coordinated phase, and code this arterial green time into PASSER II for the critical coordinated phases. To obtain the coordination signal solution, make a new optimization run.

4. **Check Minimum Time** The minor coordinated phase may be increased, if required, by reducing the conflicting left turn and giving this extra green time to the minor coordinated phase.

5. **Balance Cycle Length** If the minor coordinated phase for the arterial is shorter than the major critical coordinated phase, then a similar adjustment should be made by reducing conflicting left turn time by a desired amount and adding this reduction time to the through phase.

6. **Test Timing Interval** To accommodate the minor coordinated green, each of the reduced phases should be checked to see if the new volume-capacity ratio has exceeded the targeted v/c ratio.

7. **Field Timing Adjustment** Although PASSER II was originally designed for progression analysis in a fixed time system, this analysis procedure allows the user to satisfy the requirements for the critical traffic phase(s) with some targeted v/c ratio, and effectively utilize the remaining green times for progressive movements.

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PRETIMED CONVERSION STRATEGY

When the user completes data collection or field estimation of the average green times, the PASSER II program data should be prepared for the actuated operations as follows.

1. **Average Phase Interval** First, determine the "average variable interval durations" for each signal phase by using the measured actual green of the fixed intervals from the controller settings or estimated phase lengths from experience. For example, if the average split from the signal timing data is 12 seconds, and the clearances are 5 seconds, then the variable interval is 7 seconds.

2. **Coordination Offset** Second, calculate the "Yield-Points" or the "Desired Offsets" for achieveing certain level of arterial progression and record synchronous phase settings, including the existing coordination offsets and estimated average green times.

3. **Pedestrian Timing** Calculate "minimum phase lengths" in seconds, from maximum of both vehicular and pedestrian clearance. The vehicular clearance phase is equal to the minimum assured vehicular green plus clearance intervals. The pedestrian clearance interval is equal to the minimum time needed for pedestrian crossing plus clearance intervals.

    Ignore this value if signal operation, on the average, is not influenced by pedestrians. Code minimum green times into PASSER II-90 as the minimum phase lengths for vehicle movements. Code minimum phase length to satisfy minimum pedestrian requirements, if the green times are higher at intersections with high pedestrian activity.

4. **System Evaluation** A "system evaluation" must be performed to develop the coordination timing plans and the overall system performance should be evaluated through simulation evaluation and field study. The existing background cycle length should be coded as the system cycle length into PASSER II-90 model. After the optimization run, please summarize the results on the data reduction sheet.

5. **Field Evaluation** A field evaluation should be conducted with minor adjustments to green splits as necessary, since the estimated degrees of saturation may be slightly higher than the assumed 85% for side streets. Otherwise, the main street may become oversaturated due to the lack of available green times to favor arterial progression.

6. **Field Timing Adjustment** For practical coordinated, actuated signal systems, control strategies and experience may be different at various locations. The use of semi-actuated control is implemented through time-of-day control based on arterial progression needs during peak-hour based on pretimed analysis. All intersections may be operated in isolated actuated mode for light traffic and late night.

COORDINATED ACTUATED SIGNAL CONTROLLER TIMING SETTINGS		
NO	ITEM	FUNCTIONAL DEFINITION
1	YIELD POINT	The earliest point at which the coordinated phase may end to give right of way to one or more of the opposing phases.
2	FORCE-OFF	Fixed points in the background cycle length used to terminate the duration of the actuated phases, guaranteeing a green window for the coordinated phase to provide for arterial progression.
3	GREEN SPLIT	A division of the cycle length allocated to each of the various phases. Can be expressed for arterial progression.
4	COORDINATION OFFSET	Time relationship expressed in seconds or percent of cycle length, determined by the difference between a defined interval portion of the coordinated phase green and a system reference point.
5	PHASE INTERVAL	A part of the signal cycle during which the signal indication does not change.
6	REFERENCE OFFSET	Point for which offset is calculated from the start of coordination phases 2 or 6 or, phases 4 or 8.
7	PHASE	The controller sees each phase as individual movements. Total of eight (8) possible phases can be designated at each intersection for left turn and through movements, respectively. Concurrent phases are protected, non-conflicting phases that are timed together, such as "1 + 5", represent phase number 1 and number 5 running together at the same time.
8	PHASE REVERSAL	For an 8 phase dual ring controller, in some cases, phases 1 and 2 in ring 1 could be reversed. The existing 1+5 phase would become 2 + 5.

Figure 6. Coordinated Actuated Signal Timing Parameters.

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V. EVALUATION TECHNIQUE

System before-and-after evaluation must be performed to examine the overall performance. Both simulation evaluation and field study may be needed. The evaluation may be summarized on the example data reduction sheet as shown in **Figure 7. "Signal System Improvement Evaluation"** (Page 20). Simulation models can not replicate many field situations completely, therefore, approximated approach volumes and selected observations are needed. The field studies should be considered as a verification and validation stage.

FIELD STUDY

The recommended methods are the **floating car study** and **spot intersection delay study.** These field studies, as described in the 1985 HCM, should include data collection on the total travel time between each signal, stopped delay at each signal, total number of stops, and reasons for all stops and other travel interference. Disregard all data significantly affected by external factors. Perform counts along study route and major cross streets.

Stopped Delay Study

Stopped delay studies may be conducted on selected cross streets by recording the queue at 15 second intervals, the total approach volume and total number of vehicles that were required to stop. **Figure 8. "Stop Delay Data Collection Form"** (Page 21) is an example of the data collection format.

Floating Car Study

Figure 9. "Travel Time Data Collection Form" (Page 22) is a recommended format for floating car studies. Record the travel time between each intersection, the stop time at each intersection, and total stops while driving a car up and down the street.   Make all attempts to match the prevailing travel speed of the traffic stream to measure the arterial system progression quality.   During field studies, four signal timing control scenarios may be tested per day. The time periods may include the Morning Peak or **"AM"** (7:00 a.m. to 9:00 a.m.), Noon Peak (11:00 a.m. to 1:00 p.m.), Evening Peak or **"PM-1"** (4:00 p.m. to 5:00 p.m.), and Evening Peak or **"PM-2"** (5:00 p.m. to 6:00 p.m.).

STUDY TOOLS

Two programs, FLOATCAR and FLOATPRO, can be used to facilitate field data collection, reduction and analysis to improve the data collection effort and ensure data reliability. The programs performed well during this project data collection effort, and are recommended for future usage. FLOATCAR is a user-friendly menu-driven program that eases floating car field data entry. This program can be used in any IBM Compatible PC. The data collected can be processed using FLOATPRO program. The output from the FLOATPRO program consists of a comma-separated file tabulating the details of the run, the travel times recorded at each intersection, and total stopped delays during different runs. The average travel times and numbers of stops for a set of runs in different directions are provided for immediate processing.

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SUMMARY OF ESTIMATED TRAFFIC SIGNAL SYSTEM IMPROVEMENTS								
SYSTEM PERFORMANCE MEASURES		VEHICULAR STOPS (STOPS)		TOTAL SYSTEM DELAY (VEH-HRS)		FUEL CONSUMPTION (GALLONS)		
		BEFORE	AFTER	BEFORE	AFTER	BEFORE	AFTER	
HOURLY VALUES	AM							
	PM							
	OFF							
DIFFERENCES	AM							
	PM							
	OFF							
HRS/DAY	AM							
	PM							
	OFF							
DAILY TOTALS	AM							
	PM							
	OFF							
	TOTAL							
UNIT VALUES								
ANNUAL COST SAVINGS								

TOTAL ANNUAL COST SAVINGS: _____

BTU'S REDUCED: _____

SYSTEM B/C RATIO: _____

Figure 7. Signal System Improvement Evaluation.

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INTERSECTION STOP DELAY STUDY

STUDY: _____ LOCATION: _____ PAGE: ___ OF ___
DATE: ___/___/___ TIME: AM__OFF1__OFF2__PMOBSERVER: _____
                        7-9   10-12   1-3   4-6

NO	TIME PERIOD (HR:MIN)	NUMBER OF VEHICLES STOPPED IN APPROACH AT TIME				APPROACH TOTAL	
		+ 0 SEC	+ 15 SEC	+ 30 SEC	+ 45 SEC	NO. STOP	NO. PASS
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
TOTAL							
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
TOTAL							

SUMMARY OF STOPPED DELAY STUDY

TOTAL DELAY	=	TOTAL NUMBER QUEUED VEHICLES * 15 SEC	=
AVERAGE DELAY	=	TOTAL DELAY / APPROACH VOLUME	=
% STOPPED	=	NUMBER QUEUED / APPROACH VOLUME	=

Figure 8. Stop Delay Data Collection Form.

TRAVEL TIME FIELD DATA COLLECTION WORKSHEET

Arterial_____ Date_____

Driver_____ Recorder_____ Direction_____

Signal Location	Distance (Mile) (Feet)	Run No.___ Time_____ CUM/TT (sec)		Stop Time (Sec)	Run No.___ Time_____ CUM/TT (sec)		Stop Time (Sec)	Run No.___ Time_____ CUM/TT (sec)		Stop Time (Sec)

Note -   Coding for small squares in CUM/TT columns:

S   - Signal (lower box)
LT   - Left Turn (upper box)
P   - Pedestrian (upper box)
PK   - Parking (upper box)
4W   - 4-Way Stop (upper box)

Figure 9. Travel Time Data Collection Form

MEASUREMENTS OF EFFECTIVENESS

To quantify the system performance, use a number of recommended measures of effectiveness. Appropriate technique depends on study site, measurement, data-collection crew size, and length of intersection approach to be observed. Please see Figure 10 (Page 24) and Appendix for more details on the system mmeasurements of effectiveness for operational evaluation.

Saturation Ratio

To represent various volume loadings, volume-to-capacity or saturation ratios can be used to represent typical operations and loading conditions throughout different times-of-day.

Progression Efficiency

Progression efficiency is defined as the ratio of the available progression bandwidth to the cycle length, expressed as a percentage. A progression efficiency of 30% to 40% is considered good. Anything beyond these limits may be acceptable only if the arterials have the most priority.

Delay

As described in the TRB "Highway Capacity Manual," delay is a disutility measure, expressed in seconds or hours lost on a per vehicle basis. Generally, the higher the delay, the worse the system, Stop delay is the difference between the time a vehicle takes to clear a system and the time it would have done so if it had traveled without stopping. Stopped time delay is the time the vehicle spends stopped at the intersection. Approach delay is the sum of time lost in acceleration, deceleration, and stopped delay. Time-in-queue delay is the time spent in queue taken to clear the intersection.

Stops

This disutility measure, expressed in number of times the vehicular speed drops below 2 miles per hour, is considered to be the stops incurred.

Fuel Consumption and Emissions

The fuel consumed by the vehicle traveling through the system is a common disutility measure. The corresponding air quality measures, expressed in nitrogen dioxide (NOx), hydrocarbons (HC) and carbon monoxide (CO), are other important disutility factors that will affect environmental protection.

Combined Measures

Other measures, such as total volumes, travel speeds, saturation ratios, cycle length, green utilization, and combined indicators, such as S-Index, can be used. As shown in Figure 10. "S-Index," the S-Index combines the total time, stops, fuel consumption, carbon monoxide, nitrogen oxides, and hydrocarbons, into total society cost for operating a traffic signal system.

S-INDEX

To combine all the relevant performance measures, a monetary value is developed and proposed as a measure that can better reflect the total system operating cost to society. The S-Index can be used to compare systems and control strategies based on the fixed dollar value and provides more meaningful persuasion to the decision maker. The combined "S-Index" calculates the dollar value on total delay, stops, fuel consumption, and emissions of Carbon Monoxide (CO), Nitrogen Oxides (NOx), and Hydrocarbons (HC).

$$SI = Kt * TT + Ks * S + Kf * F + KCO * CO + KHC * HC + KNOx * NOx$$

where
SI = S Index,
Kt = Cost of vehicle and passenger time,
Ks = Cost of a vehicle stop,
Kf = Cost of fuel,
KCO = Cost of CO emissions,
KHC = Cost of HC emissions,
$KNOx$= Cost of NOx emissions,
TT = Total Travel Time,
S = Number of stops,
F = Quantity of fuel consumed,
CO = Quantity of CO produced,
HC = Quantity of HC produced, and
NOx = Quantity of NOx produced.

Obtain these costs from various sources and keep data up-to-date. Calculate the index using acceptable dollar values as follows.

$$S \text{ Index} = \$13.2*\text{Total Time} + \$0.03*\text{Stops} + \$1.1*\text{Fuel Consumption} + \$3050*HC + \$300*CO + \$2750*NOx$$

Estimate fuel consumption from the formulas in PASSER II and TRANSYT-7F.

$$F = [0.075 - (1.5899*10^{-3}) * v + (1.50655*10^{-5}) * v**2 + 0.0122 * D + (6.14112 * 10^{-6}) v**2 * S] * 1 * V$$

where
F = Total amount of fuel consumed (gallons),
v = Free speed (mph),
D = Stopped delay (min/mile),
S = Number of Stops (stops/mile),
1 = length of route (miles), and
V = Average traffic volume along the route.

Estimate the amount of pollution generated by applying either the MOBILE 5.0, EMFAC7, Modified Winfrey Method, or newer versions.

Figure 10. S-Index.

APPENDIX. GLOSSARY

Actuation The operation of any type of detector. Operation implies the use of any output from a detector to the controller.

Advanced Actuated Controller An actuated controller that can count vehicles beyond the first. It generally has variable initial interval actuation.

Arterial Priority Options Arterial Priority Options (APO) is a feature available in TRANSYT-7F program to maximize arterial progression opportunity in the comparatively heavy coordinated movements.

Auxiliary Equipment Separate devices used to add supplementary features to a controller assembly.

Basic Actuated Controller One that cannot count vehicles beyond the first. It does not have a variable initial interval.

Bandwidth Weighting Factors Bandwidth Weighting Factors is a programming feature available in MAXBAND-86 and PASSER IV programs to provide extra priority to selected links or traffic movements.

Call A registration of a demand for right of way traffic.

Carry-Over Output The ability of a detector to continue its output for a predetermined length of time following an actuation.

Controller (1) A device which controls the sequence and duration of indications displayed by traffic signals, (2) Under computer supervision a device which switches the signal circuits according to the computer's instructions.

Controller Unit The part of the traffic controller assembly which performs the basic timing and logic functions.

Coordination The establishment of a definite timing relationship between adjacent traffic signals.

Coordination Offset Time relationship expressed in seconds or percent of cycle length, determined by the difference between a defined interval portion of the coordinated phase green and a system reference point.

Cycle Length The time required for one complete sequence of signal indications.

Delay Time lost by vehicles due to traffic friction or control devices.

Delayed Call Detector A detector that does not issue an output until the detection zone has been occupied for a period of time that has been set into the appropriate detector unit.

Delayed Output The ability of a detector to delay its output for a predetermined length of time following an actuation.

Density A measure of the number of vehicles per unit length of roadway.

Density Controller Actuated controller that has timing adjustments for the selection of the allowable gap independent of the passage time. A volume-density controller and a modified density controller are each a type of density controller.

Design Speed The speed used as typical by the designer of the detector/controller scheme, under free traffic flow conditions.

Detection Zone The area of the road within which a vehicle will be detected by a vehicle detector.

Detector A device for indicating the presence or passage of vehicles and pedestrians.

Detector Failures The occurrence of detector malfunctions including non-operation, chattering, or other intermittent erroneous counting.

Dilemma Zone Protection Any method attempted to control the end of green interval so that the vehicle will be avoided in the dilemma zone when the signal turns yellow.

Dilemma Zone A distance of time interval related to the onset of the yellow interval. That portion of the roadway within which a driver is indecisive regarding stopping prior to the stopline or proceeding into or through the intersection. It is sometimes expressed as the increment of time corresponding to the dilemma zone distance.

Dummy Interval A redundant interval in the cam-switching mechanism to allow the total number of intervals in the cycle to correspond integrally with the total number of intervals on the cam-switch mechanism.

Emergency Vehicle Preemption The transfer of the normal control of signals to a special control mode for emergency vehicles.

Extended Call Detector A detector with carryover output. It holds or keeps the call of a vehicle for a preset time interval. It can be set to time before the vehicle enters the detection area or after the vehicle leaves the detection area.

Force-Off Fixed points in the background cycle length used to terminate the duration of the actuated phases, guaranteeing a green window for the coordinated phase to provide for arterial progression.

Force-Off Command A system command which forces the termination of a phase of a traffic signal.

Green Split A division of the cycle length allocated to each of the various phases. Can be expressed for arterial progression.

Gap Reduction A feature whereby the unit extension or allowed time spacing between successive vehicle actuations on the phase displaying the green in the extensible portion of the interval is reduced.

Gap-Out Termination of arterial green due to maximum number of vehicle actuations so green may be served to a competing phase.

Hold A command to the controller which causes it to retain the existing right-of-way.

Interval The part or parts of the signal cycle during which signal indications do not change.

Locking Detection Memory A selectable feature of the circuit design for a controller phase whereby the call of the vehicle arriving on the red or yellow is held by the controller after the vehicle leaves the detection area until it has been satisfied by the display of a green interval to that phase.

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

Loop Occupancy Controller A detector or controller design using long detection loops (normally 30 ft or longer) and detector units operated in non-locking mode. A loop occupancy controller may, but not necessarily, be designed to rest in all red in the absence of any traffic demand.

Main Street Green Data sent from the intersection controller to the computer indicating that the controller is displaying a green signal to the main traffic phase.

Maximum Green The maximum green after the opposing actuation, which may start in the initial portion, after which the phase would be terminated.

Measurement of Effectiveness (MOE's) Indices of performance effectiveness of the system in improving traffic flow. Common bases of comparison include congestion, density, lane occupancy, stops, delay, and queue length.

Non-Locking Detection Memory A selectable feature of the circuit design for a controller phase whereby the call of a vehicle arriving on red (or yellow) is forgotten or dropped by the controller as soon as the vehicle leaves the detection area.

Occupancy The percentage of roadway occupied by vehicles at an instant in time. In general use, it is a measurement based upon the ratio of vehicle presence time (as indicated by a presence detector) over a fixed period of total time.

Offset The time difference or interval in seconds between the start of the green indication at one intersection as related to the start of the green interval at another intersection or from a system time base.

Passage Mode Detector mode in which an output is given as long as a vehicle remains in the field of influence. Also called Presence Mode.

Passage Period The time allowed for a vehicle to travel at a selected speed from the detector to the nearest point of conflicting traffic.

Pattern A unique set of traffic parameters (cycle, split, and offset) associated with each signalized intersection within a predefined group of intersections (a section or a subzone).

PCPHPL Passenger Car Unit per hour of green time per lane.

Phase The part of the cycle allocated to any traffic movements or combinations of traffic movements simultaneously receiving right-of-way during one or more intervals. The controller sees each phase as individual movements.   Total of eight (8) possible phases can be designated at each intersection for left turn and through movements. Concurrent phases are protected, non-conflicting phases that are timed together, such as "1+5", represent phase number 1 and number 5 running together at the same time.

Phase Interval A part of the signal cycle during which the signal indication does not change.

Phase Overlap Refers to a phase which operates concurrently with one or more other phases.

Phase Reversal For an 8 phase dual ring controller, in some cases, phases 1 and 2 in ring 1 could be reversed.   The existing 1+5 phase would become 2+5.

Phase Sequence The order in which a controller cycles through all phases.

Preemption The term used when the normal signal sequence at an intersection is interrupted and/or altered in deference to a special situation such as the passage of a train, bridge opening, or granting the right-of-way to an emergency vehicle.

Presence Detection The ability of a vehicle detector to sense that a vehicle has appeared in this field whether moving or stopped.

Presence Loop Detector   An induction loop detector which is capable of detecting the presence of a standing or moving vehicle in any portion of the effective loop area.

Presence Mode Detector mode in which an output is given as long as a vehicle remains in the field of influence. Also called Passage Mode.

Pulse Mode Detector mode in which a short output is given when detection occurs.

Real Time Control The processing of information of data in a sufficiently rapid manner so that the results of the processing are available in time to influence the process being monitored or controlled.

Recall An operational mode for an actuated intersection controller in which a phase, either vehicle or pedestrian, is displayed every cycle whether demand exists or not. Usually used during a temporary or emergency situation.

Red Rest A controller designed to rest in all red in the absence of any traffic demand.

Reference Offset Point for which offset is calculated from the start of coordination phases 2 or 6 or, phases 4 or 8.

Skip Phasing The ability of a controller to omit a phase from its cycle of operation in the absence of demand or as directed by a master control.

Slave A local control device whose interval timing and sequence of operation is controlled by a submaster in a distributed system.

Split A percentage of cycle length allocated to each of the various phases in a signal sequence.

Stops The number of times vehicles stop in the system.

Time Headway The time separation between vehicles approaching an intersection, measured from the front of a vehicle to the next vehicle.

Time-of-Day Patterns Signal timing plans selected according to the time of day.

Traffic Detector A device by which vehicles, street cars, trolley buses, or pedestrians are enabled to register their presence with a traffic actuated controller.

Traffic Responsive System A system in which a master controller specifies the cycle and offset based on real-time demands of traffic as sensed by vehicle detectors.

Variable Initial Interval A controller design feature which adjusts the duration of initial interval for the number of vehicles in the queue.

Volume Density Controller An actuated controller which, in its two phase model, has three gap-reduction factors, namely, Time Waiting, Cars Waiting, and Density.

Yield The action of allowing a semi-actuated controller, or an actuated controller operating in the semi-actuated mode, to terminate the main street phase to begin satisfying existing cross-street demand.

Yield Point The earliest point at which the coordinated phase may end to give right of way to one or more of the opposing phases.