INNOVATIONS IN ACTUATED SIGNALIZ
DIAMOND INTERCHANGE CONTROL

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ABSTRACT

The operational features of three-phase and four-phase diamond interchange signal control are evaluated in this paper. Site characteristics, data collection methods, and procedures employed for the study are described. General descriptions are presented of the traffic volumes, cycle lengths, traffic delays, and queue characteristics observed for three- and four-phase control at four diamond interchanges. An assessment of traffic signal phasing is described in terms of operational effects on queues, cycle lengths, and multistops.

It was concluded from the traffic studied and for the operational environment experienced that three-phase control, in general, resulted in less delay, fewer stopped vehicles and shorter cycle lengths than four-phase control for a given traffic volume.

Further, the characteristics of queue, traffic volume, and three- and four-phase control at diamond interchanges revealed that three-phase or four-phase control may not be appropriate under certain interchange geometrics and traffic conditions. Specifically, three-phase control may not be proper for those interchanges having extremely short distances between signals and no separate left-turn bays between signals. Similarly, four-phase control may not be appropriate for those interchanges which are located short distances away from freeway exit and entrance ramps.

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Diamond interchanges are widely used in urban areas as a means to transfer freeway traffic to and from the surface street system. These interchanges are almost always signalized with traffic actuated or pretimed controllers using a variety of signalization strategies. This paper addresses this complex subject and seeks to provide useful information for guiding future engineering decisions regarding the selection and specification of types of diamond interchange control.

Diamond interchange control has been discussed for many years with a variety of strategies applied in attempts to move traffic efficiently (1). Much research has been performed to determine the most effective signal phase sequences for a given type of control (2, 3, 4).

CONTROL CONCEPTS

The Texas Department of Highways and Public Transportation (TDHPT) presently implements two basic types of isolated diamond interchange controllers in the field. One is a four-phase only controller. The other is a three-phase and four-phase controller. It is not clear whether three-phase operation is superior to four-phase operation under typical Texas urban freeway conditions. The operational experiences of local Texas traffic engineers with the new three-phase and four-phase has not been determined.

Four-Phase Controller

The four-phase diamond controller used in Texas is a standard four-phase, traffic actuated NEMA controller with a user programmed overlap card and an external double clearance interval timing unit. This controller provides the popular TTI four-phase actuated plus two overlaps signal phasing presented in Figure 1. It is widely used.

The four-phase controller also utilizes an external detector switching card to change from the front set of detectors on the frontage road to the back set of detectors shown in Figure 2 when the controller is in Phase 1 (or 3) and call is received for Phase 2 (or 4). The detector switching card permits full utilization of the travel time along both the frontage road and the "on-coming" cross street movements during Interval 1 (or 3) (the "overlap phase") shown in Figure 1. The switching detector card also switches

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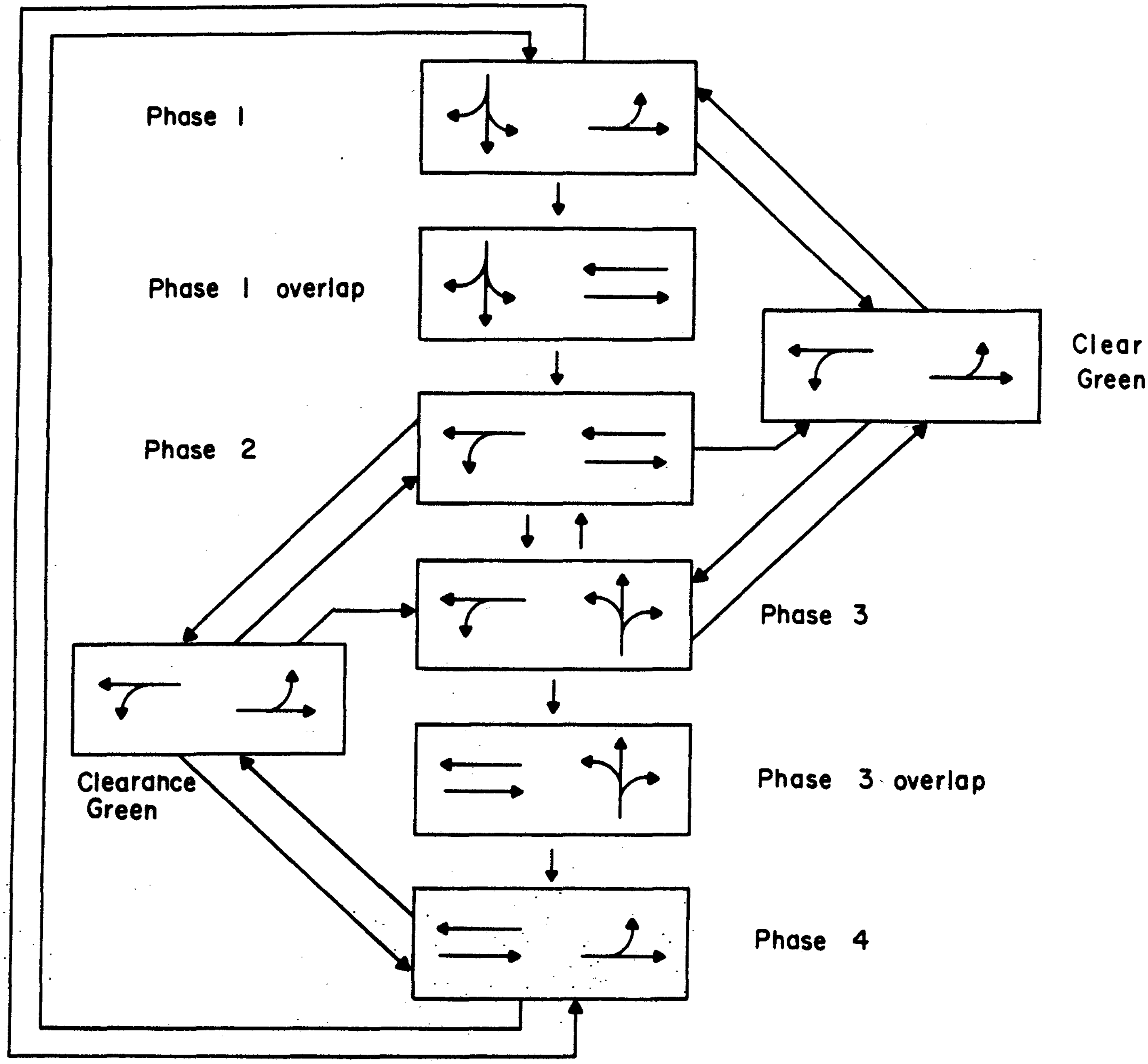

Figure 1. Four-Phase Full Traffic Actuated Diamond Interchange Phasing.

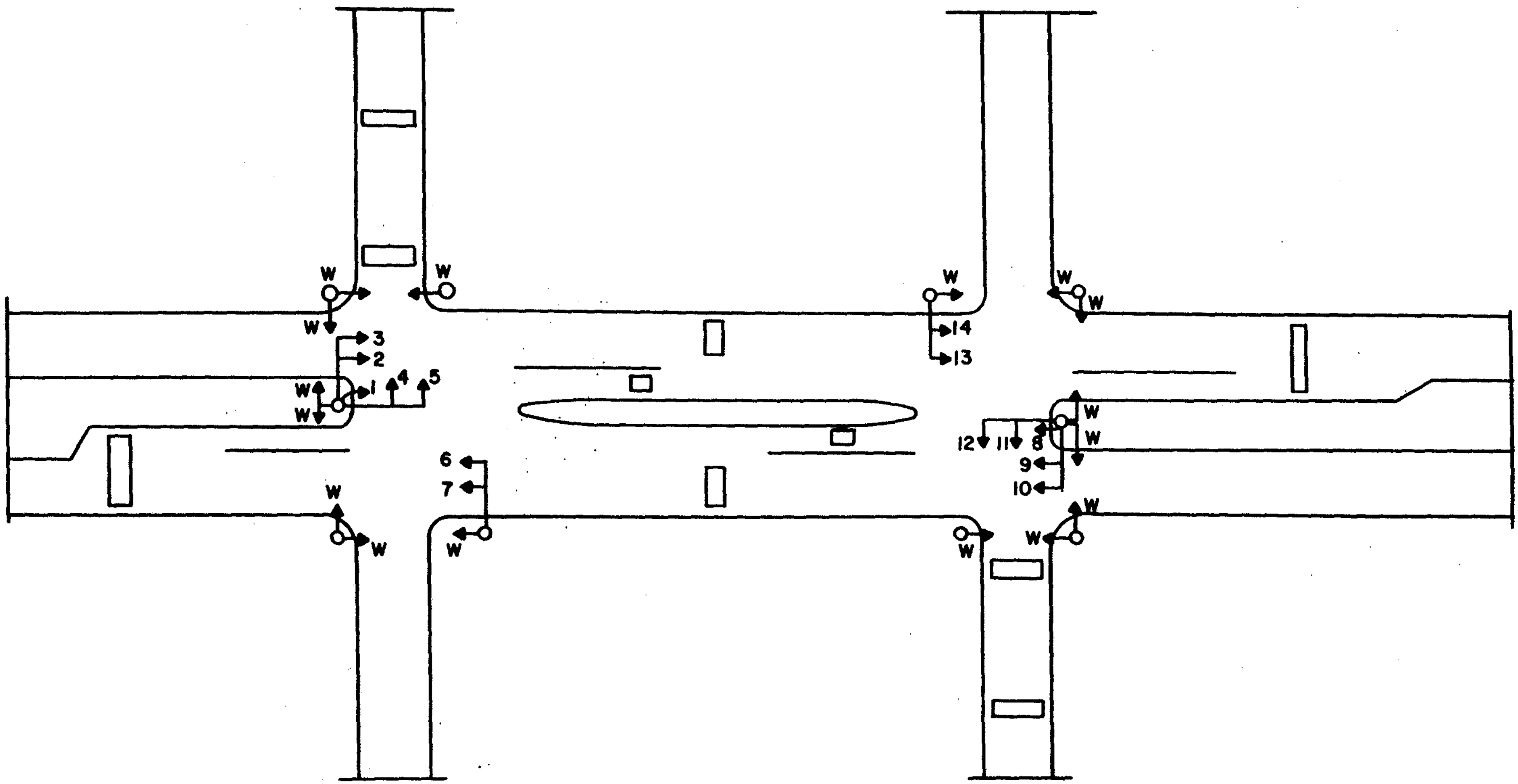

Figure 2. Detector Configuration for Four-Phase and Texas Diamond Controllers.

the detectors, located on the cross street between the frontage roads, on and off depending on which phase is in effect. Two possible maximum phase timings can be provided with the NEMA controller through the use of time clock or other external means. This controller has been installed at diamond interchanges throughout Texas and other states and is known to provide effective traffic control.

Three-Phase and Four-Phase Controller

The other basic type of diamond controller SDHPT uses features a microprocessor based unit that provides the basic four-phase TTI diamond phasing shown in Figure 1 (with refinements) and, by remote switching it also can provide the three-phase traffic actuated strategy presented in Figure 3. The change from one mode to the other can be made by time clock or, as done in Irving, Texas, by traffic responsive logic.

The phasing of the three-phase and four-phase controller, hereinafter called the "Texas Diamond", presently is provided by one NEMA eight-phase controller with special internal programming that eliminates the external detector switching card and external double clearance interval timer unit required by the aforementioned four-phase controller. A phase module is placed in the phase eight (8) position and the Minimum Green, Max. I and Max. II green time settings are used for these clearances depending on the phase rotation that occurs. No compatability line exists in this controller so that any phase in Ring 1 can be active with any phase in Ring 2. Consequently, the Texas Diamond is not compatible with the four-phase or eight-phase standard NEMA controller. About 50 of the Texas Diamond controllers providing three-phase and four-phase with overlap operations are in use in Texas.

STUDY OBJECTIVES

The initial objectives of this study were as follow: a) conduct an operational evaluation of the two types of controllers (i.e., four-phase, and three-phase together with four-phase capability) to include comparisons of vehicular delay, stops, cycle length, and response to peak flows; b) conduct a safety review of the accident experience for a representative sample of sites to determine if one control strategy is inherently safer than the other; and c) obtain other relevant competitive features of the two control strategies and controller units. This paper covers some of the operational results of the study.

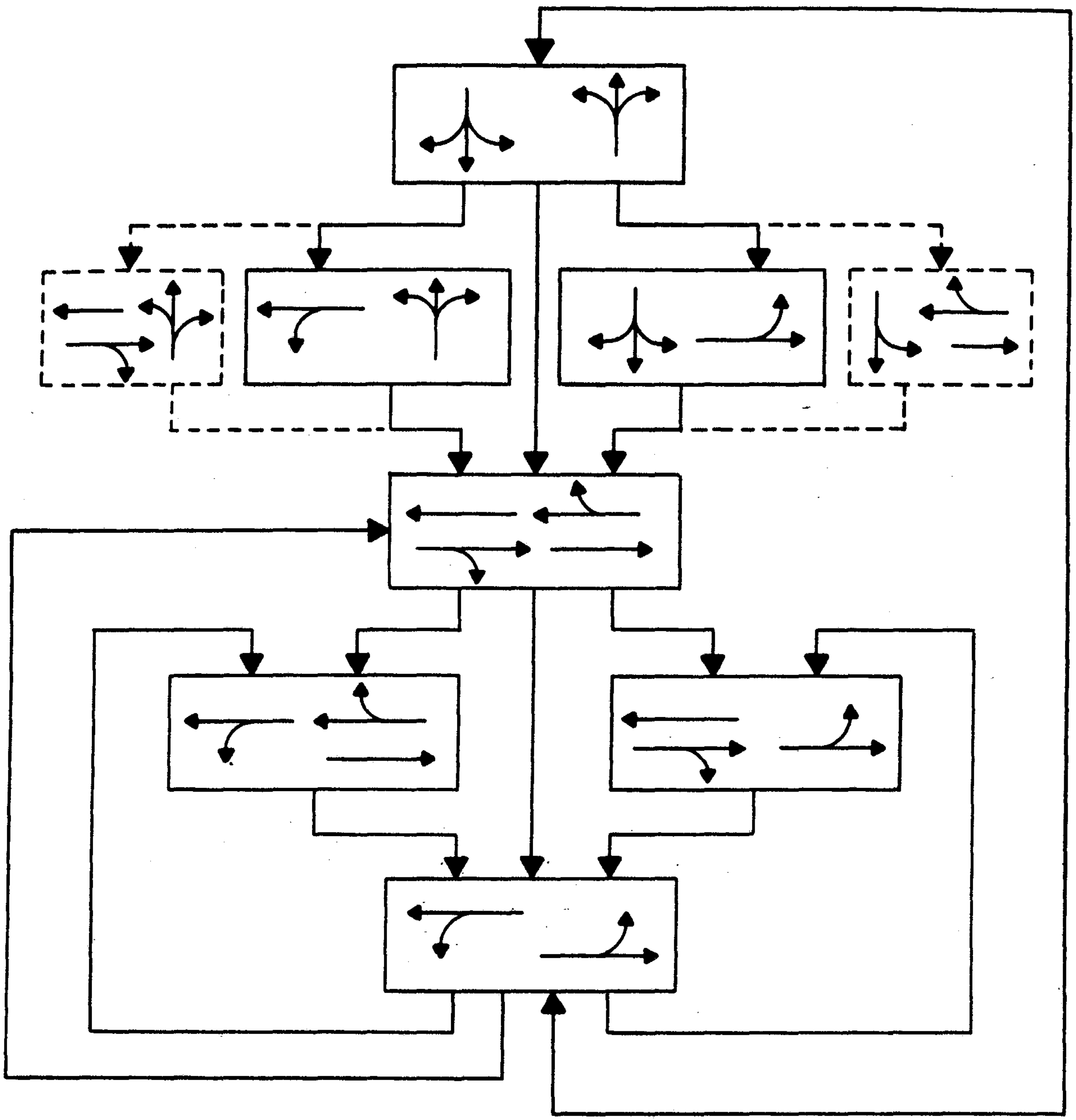

Figure 3. Three-Phase Full Traffic Actuated Diamond Interchange Phasing.

EXPERIMENTAL PLAN

Type of Control

The experimental plan primarily was developed to evaluate the operational performance of two types of diamond interchange signalization strategies: namely, 1) traffic actuated three-phase control and 2) traffic actuated four-phase with overlaps control. Figure 3 presented the three-phase pattern and Figure 1 presented the four-phase pattern. The four-phase strategy is often called "TTI four-phase overlap" signalization.

Some subjective evaluation of the TTI diamond controller and the Texas Diamond controller were obtained. Since the Texas Diamond controller can provide both three-phase and four-phase operations at the same interchange with the flip of a switch, it could be studied simultaneously with the conduct of the signal phasing evaluation.

Study Design

The study design called for the field studies to be conducted during May and June of 1982. Since many of the Texas Diamond controllers were located in the Metroplex of Dallas-Ft. Worth, it was decided early in the project to concentrate the field studies in the Metroplex. Four sites were selected for study following a site selection trip made by TTI research staff and TDHPT traffic engineers. The sites were selected to provide a variety of geometrics and traffic conditions.

The locations of the four study sites and the overall field data collection effort, as conducted, are summarized in Table 1. A wide variety of geometrics and traffic volumes were provided by the four Dallas area diamond interchanges. The interchange separation between intersections ranged from a wide 500 feet at IH 635 @ Coit Road to a narrow 230 feet at SH 183 @ Story Road.

The signalization at all sites permitted permissive left turning within the interchange. All diamond interchange controllers were tuned by the local responsible traffic engineer just prior to the field study. Three-phase operations were always operational at least one day before operational data were collected. A typical detectorization plan for the Dallas Metroplex interchanges would be as earlier given in Figure 2 for the Texas Diamond Controllers.

As Table 1 shows, the data collection plan called for a paired comparison of three-phase (3) and four-phase (4) control on subsequent days. The study plan also called for data to be collected for four hours per day from 7-8 a.m., 10-11 a.m., 12-1 p.m. and 5-6 p.m., or some reasonable on-site modification if deemed appropriate.

Table 1. Study Design Conducted for Diamond Interchange Controller Evaluation.

Interchange Location	Intersection Separation	Study Date	Week Day	Signal Control
IH 635 @ Town East Blvd. in Mesquite	400'	5-17-82	M	3
		5-18-82	T	4
IH 635 @ Coit Rd. in Dallas	500'	5-19-82	W	4
		5-20-82	Th	3
IH 35E @ Crosby Rd. in Carrollton	240'	5-24-82	M	3
		5-25-82	T	4
SH 183 @ Story Rd. in Irving	230'	5-26-82	W	3
		5-27-82	Th	4

Some modifications to the study plan were made due to unforeseen weather conditions that arose. No 7-8 a.m. studies were able to be conducted due to rain at IH 635 at Town East Blvd., IH 35E at Crosby Road, or SH 183 at Story Road. Usually an afternoon study was substituted for the 7-8 a.m. rainout although the exact time used at an interchange varied depending on the situation. For each location, however, the same time frame studied for one type of control would always be used for the other type. Construction activities along Coit Road immediately south of IH 635 totally stopped all three-phase studies after 11 a.m. on 5-20-82.

Several types of performance data were to be collected. These included traffic volumes, traffic delays, stops and cycle times. A total of 12 people plus a study supervisor were used.

Traffic volumes and stopped time delay were collected as follows. Manual traffic counts were conducted on all four inbound approaches to the interchange plus both interior intersection approaches. Additional manual observations were made every 15 seconds during the study by another person at each of the six sites of the number of vehicles stopped on the approach to the signal. Stopped vehicle data were recorded on scribble pads and then later reduced in the office. Preliminary testing of the stopped vehicle "queue counts" suggested that eye strain might result if a short rest period was not provided more frequently than once each hour. Therefore, the hour study duration was divided into two 30 minutes intervals separated by a five minute rest break. Each 30 minute period thus became a separate study. This plan had the advantage of being better able to capture the peak period conditions.

Cycle times, cross street green times, and general observations of traffic flow on the cross street passing through the interchange were obtained by timelapse photography at all six sites. Time of day to the nearest second is displayed and recorded on each film frame. Traffic operations were filmed at one frame per second permitting one hour of traffic study per roll of film. Timelapse cameras were positioned on the cross street's two exterior approaches to each interchange and were aimed to provide a view of both the traffic signal control and traffic movements. Following film processing, data reduction was performed using a Model 3420 Timelapse data analyzer and projector system. In the data reduction process, the data obtained at Coit Road in Dallas revealed a tendancy of observation and recording error along with missing data. Thus, Coit Road data was eliminated in the subsequent statistical analysis.

STUDY RESULTS

Presentation of the field study results follow. Characterization of the traffic observed at each interchange will introduce the findings. Cycle times and traffic delays are then presented. Detailed statistical results by type of signal control conclude this section.

Traffic Volumes

Traffic counts were made at each of the four intersection approaches to each interchange. Total approach volumes were obtained for 30 minute time periods and expanded to an equivalent hourly flow rate. These 30 minute "volumes" are the basic volume measure used in this study.

Table 2 presents the range of total volumes observed at the four interchanges. The four interchanges are sequenced according to rank of highest volume levels. Total volume is the sum total of the six count station's expanded volumes. Two interchanges, SH 183 at Story Road, and IH 635 at Town East Blvd. have similar volume levels. IH 35E at Crosby Road experienced lighter traffic volumes.

Traffic Delays

Traffic delays were observed at each of the six intersection approaches to each interchange. The number of stopped vehicles were counted every 15 seconds during a 30 minute time period. To account for the different numseconds at the six stations of the interchange. It should be noted that traffic delay on an approach is an average value across all lanes and not a critical lane value.

Table 3 presents the range of traffic delay in terms of the average number of vehicles stopped per lane at the four interchanges for observed average cycle time. Traffic delays observed were ranged from 1.1 to 14.6 vehicles stopped per lane (or equivalent delays of vehicle seconds per lane per seconds).

Table 2. Ranking of Four Interchanges by Highest Observed Total Hourly Volume.

Rank Order	Interchange Location	Total Interchange Volume		Total Interchange Volume Per Lane	
		Highest	Lowest	Highest	Lowest
1	IH 635 @ Coit Rd. in Dallas	9,542*	4,050	4,456	1,782
2	SH 183 @ Story Rd. in Irving	6,136	3,489	2,045	1,166
3	IH 635 @ Town East Blvd. in Mesquite	5,120	3,356	1,707	1,119
4	IH 35E at Crosby Rd. in Carrollton	2,364	1,278	1,069	544

*NOTE: Highest traffic volume occurred during peak hour which was not otherwise evaluated.

Table 3. Ranking of Four Interchanges by Highest Observed Total Interchange Traffic Delay at Observed Average Cycle Time.

Rank Order	Interchange Location	Delay/Cycle Time Highest	Delay/Cycle Time Lowest
1	IH 635 at Coit Rd. in Dallas	14.3/111.9	6.9/75.9
2	SH 183 at Story Rd. in Irving	8.7/105.3	2.2/48.8
3	IH 635 at Town East Blvd. in Mesquite	5.6/64.9	2.8/49.1
4	IH 35E at Crosby Rd. in Carrollton	2.6/53.3	1.1/41.8

Queue Characteristics

It was noted in the previous discussion that the number of stopped vehicles were observed at six interchange stations (or approaches). Two stations, Stations 1 and 2, were on the arterial cross street and another two stations, Stations 3 and 4, were located on the frontage roads. The remaining two stations, Stations 5 and 6, were located between the traffic signals. Observers at the four "external" stations on the arterial street and frontage roads recorded the number of stopped vehicles for "external" traffic while observers at the two stations between the signals recorded the number of stopped vehicles for "internal" traffic.

Table 4 presents a summary of the queue characteristics observed during three hours of offpeak and one hour of peak traffic at each station for all interchanges evaluated. The ratios given in Table 4 provide comparison between types of control showing four-phase characteristics divided by three-phase. Four-phase control at the interchange of IH 35E at Crosby Road experienced 2.5 (i.e., 30.2 - 27.7) more external queue and 1.2 (i.e., 2.6 - 1.4) less internal queue than did three-phase control.

Overall four-phase at Crosby Road experienced a four percent (i.e., 31.6/30.3 = 1.04) larger queue than three-phase. At SH 183 and Story Road, four-phase resulted in 14.4 more external and 2.9 less internal queue than three-phase. Overall, four-phase at Story Road experienced a 27% larger queue than three-phase. Similar external and internal queue differences were observed for IH 635 at Town East. At the Town East interchange, four-phase produced 2.4 more external and 3.6 less internal queue than three-phase. Overall queue differences at Town East were negligible. From these

Table 4. Traffic Queue Characteristics Between Three- and Four-Phase Control.

Mean Queue Per 1000 Vehicles (4 phase/3 phase)						
Dallas Location	External Queue 1+2+3+4	Internal Queue 5+6	Total All Stations	External Queue Over Total (%)	Internal Queue Over Total (%)	Internal Volume Over Total Volume (%)
Crosby	30.2/27.7	1.4/2.6	31.6/30.3	95.6/91.4	4.4/ 8.6	34
Story	49.0/35.6	0.5/3.4	49.5/39.0	99.0/91.3	1.0/ 8.7	42
Town East	33.5/30.1	1.0/4.6	34.5/34.7	97.1/86.7	2.9/13.3	36
Mean	37.5/31.1	0.9/3.5	38.5/34.7	97.2/89.8	2.8/10.2	37
Mean Proportion	1.21	0.26	1.11	1.08	0.27	--

three interchange queue observations, it was noted that four-phase produced more external and less internal queue than three-phase. Part of the reason for larger external queues appears to be that the four-phase, in general, is characterized by longer cycle length that leads to more accumulation of external traffic waiting for right-of-way. The reason for less internal queue for four-phase appears to be due to a better offset system between the two signals than is provided by three-phase.

For the three interchanges studied in Dallas, it is seen in Table 4 that over 86.7 percent of an interchange traffic queue is generated at the arterial and frontage road external stations. The remaining traffic queue of less than 13.3 percent was observed at the internal stations located between the two traffic signals at an interchange. Further, since the traffic volumes at the internal stations comprise an average of 37 percent of all interchange traffic, the reduced queue per 1000 vehicles at the external stations will significantly reduce all interchange vehicles stopped than the same amount of reduction in internal queue per vehicle.

The average queue characteristics of all interchanges in Dallas by station for three-phase and four-phase control is illustrated in Figure 4. For external traffic, three-phase control saved 6.4 stopped vehicles per 1000 vehicles compared to four-phase. For internal traffic, four-phase control saved 2.6 stopped vehicles per 1000 vehicles compared to three-phase. From these queue differences, it is seen that four-phase control increased interchange traffic queue by 3.8 stopped vehicles per 1000 vehicles.

CONCLUSIONS

The following conclusions were drawn from the data collected and field observations made within this study. They apply within the volume levels studied and operational environment experienced.

(1) Queue characteristics at diamond interchanges revealed that over 86.7 percent of an interchange traffic queue is generated at the arterial and frontage road external stations. The remaining traffic queue of less than 13.3 percent was observed at the internal stations located between the two traffic signals at an interchange.

(2) Traffic characteristics at diamond interchanges revealed that traffic volumes at the external stations comprise an average of 60 percent of all interchange traffic.

(3) From queue and traffic characteristics at diamond interchanges, it is noted that the reduced queue at the external stations will significantly reduce all interchange vehicles stopped than the same amount of reduction in internal queue per vehicle.

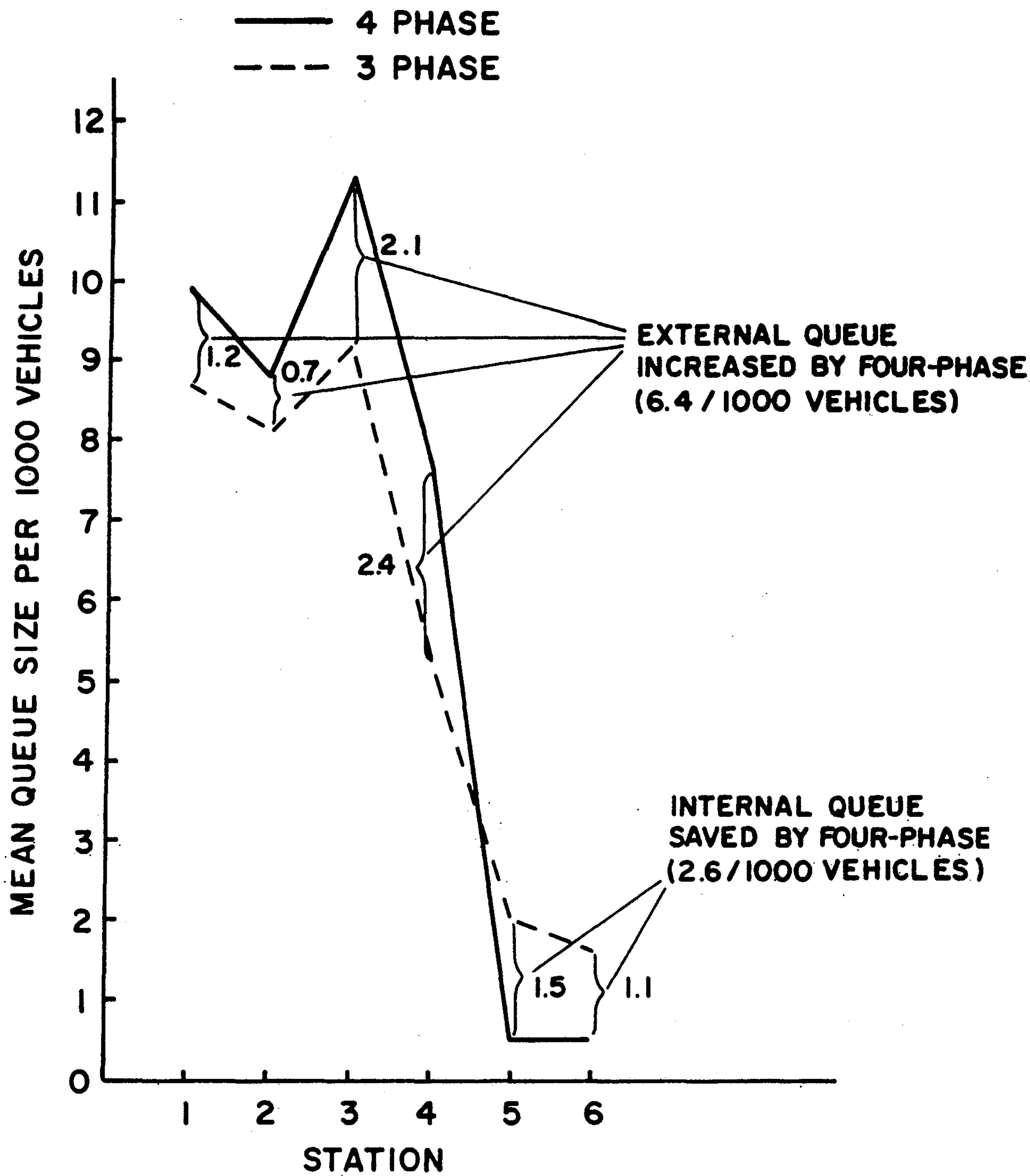

Figure 4. Average Queue Characteristics of All Interchanges in Dallas for Three and Four-Phase Control.

(4) As expected, three-phase control at diamond interchanges increased internal queues and decreased external queues while four-phase control decreased internal queues and increased external queues.

(5) The magnitude of internal queues is very small (i.e., less than 1.0) compared to that of external queue (i.e., less than 10.0) generated at a diamond interchange. Thus, the external queue dominated the stop characteristics at diamond interchanges.

(6) The characteristics of queue, traffic volume and three- and four-phase control at diamond interchanges imply that three-phase control or four-phase control is not appropriate for interchanges having certain geometrics. Specifically, three-phase control may not be proper for those interchanges having extremely short distances between signals and no separate left-turn bays between signals. Similarly, four-phase control may not be appropriate for those interchanges which are located short distances away from freeway exit and entrance ramps.

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