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16. Abstract

DARTS is an auxiliary solid-state electronic timing and switching device which can be connected directly to any modern (NEMA Standards) full-actuated traffic signal controller for the purpose of coordinating the timing of pairs of such controllers at adjacent intersections in such a way that progressive movement is provided for platoons of traffic traveling along an artery. No modification of the basic controller installation nor timing is required, and only one pair of conductors is needed to transmit the necessary platoon identification information from the upstream intersection. Functioning of the platoon identification and progression timing sequence provided by DARTS is described in the report along with functions which monitor traffic on conflicting phases in order to preclude excessive delays and queue buildups from occurring on these approaches. The results of field observations made in San Antonio while two early versions of DARTS were being evaluated are presented. Measurements of traffic volume, delay, number of stops, and speed on the arterial were recorded at four intersections during the Bandera Road study, and volume and delay observations of traffic on conflicting signal phases were also noted. Compared to normal individual intersection actuated control, there was no pronounced effect on any of these parameters either when DARTS was operated for the outbound direction only or when both outbound and inbound platoon progression was attempted simultaneously. Delay to traffic on signal phases which conflicted with artery progression was slightly higher when DARTS was operated, but not excessive.

Additional features have been incorporated into later models of DARTS, and further application of the system in appropriate situations is recommended. Proper setting of the several timers is critical; therefore, more experience is needed in order to realize the full potential of this new concept. A postscript refers to two recent installations in Texas where improved traffic performance is reported.

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by

Clyde E. Lee

Research Report Number 243-1F

Coordination of Actuated Traffic Signals

Research Project 3-18-78-243

conducted for

Texas
State Department of Highways and Public Transportation

in cooperation with the
U. S. Department of Transportation
Federal Highway Administration

by the

CENTER FOR TRANSPORTATION RESEARCH
THE UNIVERSITY OF TEXAS AT AUSTIN

August 1982

The contents of this report reflect the views of the author, who is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

There was no invention or discovery conceived or first actually reduced to practice in the course of or under this contract, including any art, method, process, machine, manufacture, design or composition of matter, or any new and useful improvement thereof, or any variety of plant which is or may be patentable under the patent laws of the United States of America or any foreign country.

ABSTRACT

DARTS is an auxiliary solid-state electronic timing and switching device which can be connected directly to any modern (NEMA Standards) full-actuated traffic signal controller for the purpose of coordinating the timing of pairs of such controllers at adjacent intersections in such a way that progressive movement is provided for platoons of traffic traveling along an artery. No modification of the basic controller installation nor timing is required, and only one pair of conductors is needed to transmit the necessary platoon identification information from the upstream intersection. Functioning of the platoon identification and progression timing sequence provided by DARTS is described in the report along with functions which monitor traffic on conflicting phases in order to preclude excessive delays and queue buildups from occurring on these approaches.

The results of field observations made in San Antonio while two early versions of DARTS were being evaluated are presented. Measurements of traffic volume, delay, number of stops, and speed on the arterial were recorded at four intersections during the Bandera Road study, and volume and delay observations of traffic on conflicting signal phases were also noted. Compared to normal individual intersection actuated control, there was no pronounced effect on any of these parameters either when DARTS was operated for the outbound direction only or when both outbound and inbound platoon progression was attempted simultaneously. Delay to traffic on signal phases which conflicted with artery progression was slightly higher when DARTS was operated, but not excessive.

Additional features have been incorporated into later models of DARTS, and further application of the system in appropriate situations is recommended. Proper setting of the several timers is critical; therefore, more experience is needed in order to realize the full potential of this new concept.

SUMMARY

Along some arterial routes, basic actuated signal controllers are used at adjacent intersections for traffic control, but no provisions are made for assuring that platoons of traffic on the arterial move progressively through the series of intersections without stopping. Harvey J. Beierle conceived a technique for accomplishing progressive platoon movement in these situations and constructed a pilot model of the hardware for implementing the idea in 1975. The pilot model included only three timers for predicting the progress of the platoon on the arterial.

A second generation of equipment which included monitoring timers for traffic on phases which conflicted with the arterial phases was constructed and installed on Bandera Road in 1978. This section of arterial contained four intersections with basic full-actuated signal controllers and experienced heavy outbound directional traffic in the afternoon with heavy inbound traffic in the morning. The electronic timing and switching equipment was designated by the acronym DARTS, formed from the first letters of Dynamic Arterial-Responsive Traffic System. A study of traffic volumes, delays, stops, and speeds of traffic on Bandera Road was made in November 1978 in three Wednesday afternoons. Traffic volumes and delays to traffic on the cross streets and on left-turn approaches were also measured. Three operational conditions of traffic control were observed: (1) DARTS off, normal actuated controller operation at all intersections; (2) Outbound DARTS on, to favor platoon progression in the outbound direction; and (3) Outbound and Inbound DARTS on, to provide platoon progression in both directions on the arterial if platoons of significant size formed.

Analysis of the survey data showed that traffic volumes at the site were quite consistent on all three Wednesday afternoons when the various DARTS conditions were operational. Stopped-time delay and average delay were nearly the same magnitude regardless of whether DARTS was operational or not. A slight reduction in the percent of vehicles stopped was noted for the condition when outbound DARTS alone was operational in comparison to the other two conditions, and there was about a 3 to 5 mph increase in the average speed

on Bandera Road for this condition. These variations are not of sufficient magnitude to say that DARTS was highly effective in improving traffic flow on the arterial at this study site. Even though the delays to traffic on the cross streets and in the left-turn lanes was slightly higher when DARTS was on, they were not excessive.

The second-generation DARTS that was evaluated in the field study on Bandera Road did not incorporate several features that have been added since that time, nor had much experience been gained in setting the various timers in DARTS. Further applications of DARTS in appropriately selected situations is recommended in order that the full potential of this new concept can be evaluated. Detailed descriptions of DARTS functions are given in the report, and a new specification for DARTS prepared by the Texas State Department of Highways and Public Transportation in the summer of 1981 is attached as an appendix.

IMPLEMENTATION STATEMENT

The evaluation study of second-generation DARTS equipment conducted on Bandera Road in San Antonio in November 1978 showed very small advantages, if any, for DARTS over individual intersection actuated control during the heavy directional peak traffic period. With the additional features which have since been added to DARTS, and with the additional experience which has been gained in setting the numerous timers in the DARTS units, further applications are recommended. This concept holds potential as an economical and effective means of providing coordination for platoon progression through a series of arterial intersections which normally operate under full-actuated control. Only actual field experience can prove whether the new features and refined time settings of DARTS will produce significant improvements in platoon traffic flow along the arterial without over penalizing other traffic. Adequate sampling of traffic behavior with and without DARTS supplemental control will be required for such evaluations.

A report postscript refers to recent installations and evaluations of third-generation DARTS systems in San Antonio and Corpus Christi by the State Department of Highways and Public Transportation. Dramatic improvements in traffic flow on the arterial are reported.

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CHAPTER 1. INTRODUCTION

Basic traffic actuated signal controllers are designed to operate at single, isolated intersections where traffic demands on the various approaches are expected to change significantly over time in an unpredictable or non-repetitive way. This type of controller normally receives information from vehicle detectors located a few feet in advance of the intersection and responds on a momentary basis to the arrival of vehicles by assigning the green signal indication sequentially to the approaches where a demand exists. The indication is extended incrementally as necessary to satisfy the traffic demand, or it may be extended up to a preset maximum time if vehicle arrivals are continuous and frequent throughout the interval. Only local traffic conditions near the intersection are considered by this type of controller, and no attempt is made to assure that platoons of arriving vehicles on a particular signal phase will be able to move through the intersection without slowing or stopping.

Volume-density actuated controllers incorporate additional features which allow detectors to be placed up to several hundred feet in advance of the intersection and count actuations with respect to time. The assignment and extension of the green phase is based on this information, but the zone of detection is still limited to a rather local area around the intersection. Platoons of traffic progressing toward the intersection are not assured a green indication upon arrival.

There are a number of locations in Texas where actuated controllers are utilized at two or more adjacent intersections along the same route. Since the controllers respond only to vehicle arrivals at each intersection, traffic flow along the route is not always smooth and continuous as would be desired for best efficiency and safety. Progressive movement through such a series of intersections can be achieved by installing interconnected, pre-timed controllers, but this means that the flexibility of handling varying local demands with traffic actuated controllers is lost. Also, considerable cost will normally be involved in replacing the existing actuated controllers and in installing multi-conductor interconnecting cables. Some means for coordinating the timing of actuated controllers at adjacent intersections along the same route is needed so that progressive movement can be provided when justified, but so that the normal functioning of the local controller will not be affected during those periods of time when progression is not of primary importance.

A technique for accomplishing this has been developed by Harvey J. Beierle, a traffic engineering technician in District 15 (San Antonio) of the Texas State Highway Department of Highways and Public Transportation (SDHPT). Implementation of his technique requries no modifications to the local intersection basic actuated controller if it has the force-off and phase-skip features which are normally provided on most modern actuated equipment (NEMA Standards, Ref 1). An auxiliary timing unit is simply connected to the local controller at the downstream intersection in an adjacent pair of intersections and a two-conductor cable is used to transmit information obtained from the detectors, a timer, and the actuated controller at the upstream intersection. The first hardware for this type of system was constructed in the District 15 signal shops in 1975 and installed at a pair of intersections in the San Antonio District for field trial. Apparent success of the system in moving platoons of traffic without interruption through a downstream intersection led to the initiation of a research study to evaluate the performance and potential applications of the equipment on a more extensive scale. This report describes the research that was conducted as part of the Cooperative Research Program between the Texas State Department of Highways and Public Transportation and the Center for Highway Research (now Center for Transportation Research) at The University of Texas at Austin and in cooperation with the Federal Highway Administration.

The following objectives were established for the research study:

(1) to build and install a set of hardware for coordinating the existing actuated signal controllers at two or three intersections on the same road,

(2) to make before-and-after traffic studies at these intersections and evaluate performance,

(3) to develop and evaluate modifications to the coordinating technique if necessary, and

(4) to make recommendations regarding implementation of the coordinating scheme.

The first objective was accomplished by SDHPT personnel in the San Antonio district, and the other three were undertaken by the researchers at the University in cooperation with the SDHPT personnel. Subsequent chapters of this report describe the concept and functioning of the actuated signal coordinating unit, the field studies which were conducted in San Antonio, the analysis of observed data, and the evaluation that was made of the new signal coordinating scheme.

CHAPTER 2. DYNAMIC ARTERIAL-RESPONSIVE TRAFFIC SYSTEM (DARTS)

A new concept for an actuated traffic signal controller coordination system was first developed in 1975 by Harvey J. Beierle, a senior traffic engineering tehcnician in District 15 (San Antonio) of the Texas State Department of Highways and Public Transportation. This concept was soon implemented with hardware that was designed and constructed in the District headquarters traffic signal shops and installed at two intersections in the San Antonio area. For purposes of this report, the auxiliary signal controller unit which evolved from this initial development during the next four or five years will be referred to by the acronym DARTS, which is formed from the initial letters of Dynamic Arterial-Responsive Traffic System. Several additions and improvements have been made in the original equipment, but the basic objectives of simplicity, practicality, and economy which guided the initial developments have been retained.

Whereas most previous attempts at signal coordination have involved the installation of new signal controllers and interconnecting cables, the DARTS system does not. The DARTS is simply an auxiliary timing and switching unit that is designed to be mounted in the local intersection controller cabinet. Interconnection between a pair of intersections modified with a DARTS unit for unidirectional progression requires only a single two-conductor cable to carry switch-closure information from the upstream intersection where the traffic platoon forms to the downstream intersection where the DARTS unit is located. Multi-conductor cable is normally utilized for telephone communication and for convenience of installation when bidirectional DARTS units are used.

The actual DARTS unit is a solid-state electronic device which incorporates nine electronic timing mechanisms (see Fig 1). Five of these timers are allocated to platoon detection and assurance of Main Street progression. These timers are labeled in Fig 1 as: Platoon Timer, Detector Disable Timer, T 1, T 2, and T 3. The remaining four timers deal with measuring time waiting and queue length over detectors on the cross street and in conflicting left-turn lanes so that vehicles waiting on these approaches will not be unduly

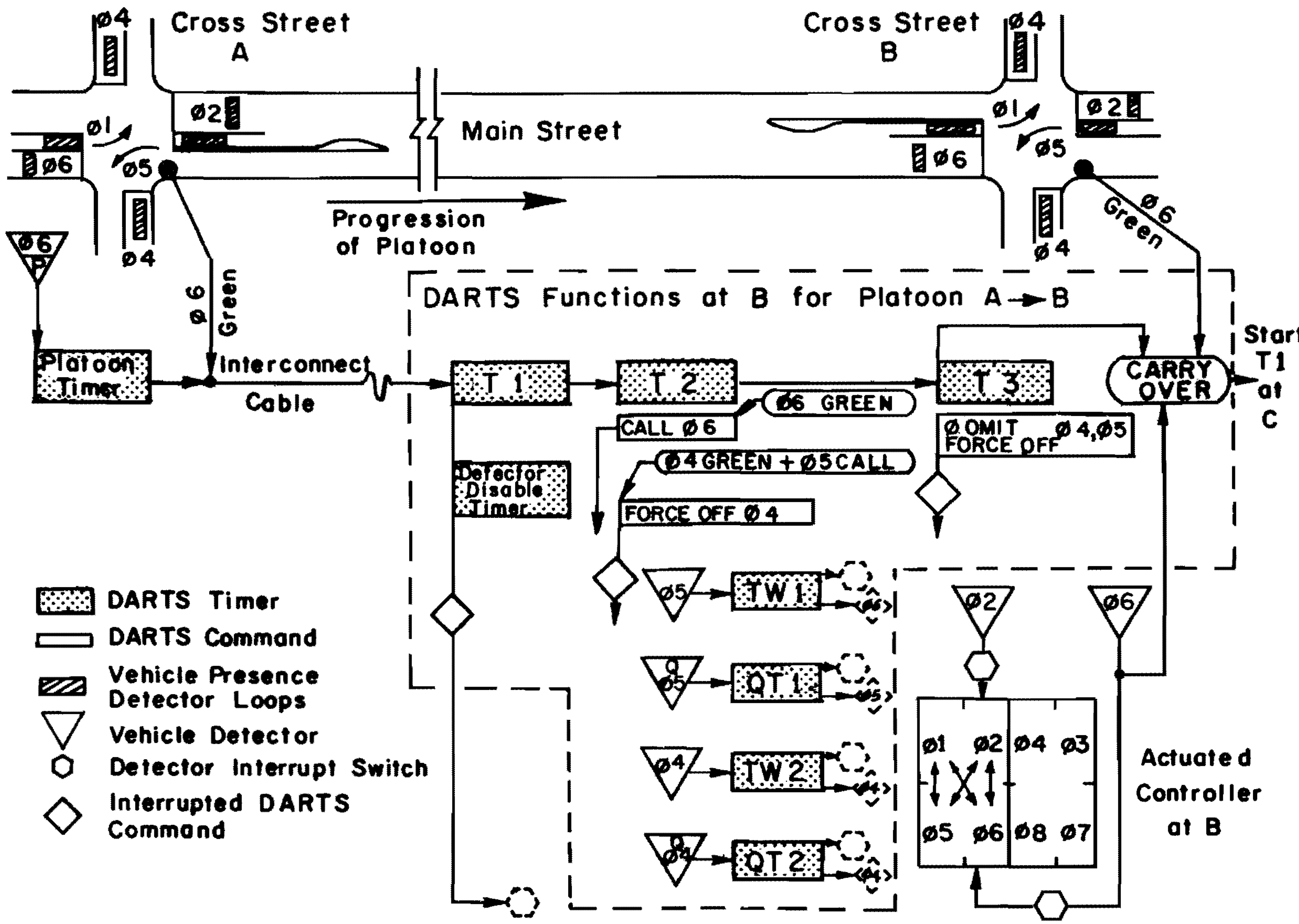


Figure 1. Functional relationship of vehicle detectors, DARTS components and actuated signal controller

penalized as a result of Main Street progression. These timers are labeled in Fig 1 as: TW 1, QT 1, TW 2, and QT 2.

The DARTS provides three functions; these are

(1) platoon identification,

(2) platoon progression, and

(3) conflicting phase evaluation.

Platoon Identification

The first DARTS function involves the identification of a platoon of vehicles at the upstream intersection. It is obvious that there must be some way to determine whether or not a platoon of vehicles is of sufficient size to warrant the implementation of the progression sequence. If such a feature were not included in the DARTS, small groups of vehicles arriving at the upstream intersection during off-peak traffic periods would trigger the progression function and possibly cause inefficiency and unnecessary vehicular delay in the system.

Platoon identification is accomplished by monitoring the vehicle detectors and the green signal indications at the upstream intersection in the direction of the desired progression. The Ø6 detector at the upstream intersection (Cross Street A, Fig 1), which will normally be set back 50 feet or more from the intersection, must be occupied continuously for at least the amount of time set on the Platoon Timer while the red indication is presented to Main Street traffic. Once a queue of standing vehicles has been thus identified, transmission of this information to the downstream intersection begins when a green indication is presented to Main Street, Ø6. The DARTS controller that is located at the downstream intersection (Cross Street B, Fig 1) responds by starting the progression sequence. If the detector occupancy interval is shorter than the time set on the Platoon Timer, the platoon is considered to be of insufficient size to warrant DARTS-induced progression. Hence, during periods when significant queues do not form on Main Street red, the DARTS progression timing sequence is not activated. Progression is provided only for platoons consisting of several vehicles.

Platoon Progression

Once a platoon of vehicles moving through the upstream intersection has been identified, the DARTS platoon progression timing sequence is initiated. This sequence consists of three successive time intervals during which the platoon is expected to travel along the main street at an appropriate speed from the upstream intersection to the downstream intersection where a green signal indication will desirably be displayed. The total of the three time intervals and the distance between intersections determines the speed of platoon progression that is provided on the main street. Figure 1 shows the relationship of the progression timing sequence.

In the first stage of platoon progression, timer T 1 is activated. During this interval, the platoon is predicted to travel to a point in time in advance of the downstream intersection beyond which there will be insufficient time for the downstream controller to terminate the Main Street green Ø6, present the associated change clearance interval, service a conflicting phase, and return to Main Street green before the platoon arrives at the intersection. The setting for timer T 1 is therefore the total time needed for the lead vehicle in the platoon to travel from the upstream intersection to the downstream intersection minus the sum of the times set on timers T 2 and T 3. The total travel time between intersections should be determined by field observation or calculated for a reasonable speed of progression.

In some situations when travel time between intersections is sufficiently long, it is desirable to prepare the downstream intersection for the pending arrival of a platoon on Main Street by permitting conflicting phases to be serviced while the approaching platoon is in a non-critical location. This is accomplished in DARTS with the Detector Disable Timer, which starts simultaneously and runs concurrently with timer T 1. During the interval when the Detector Disable Timer is operating, the approaching platoon is well upstream and Ø2 and Ø6 detectors at the downstream intersection are temporarily disconnected from the controller. Thus, in the apparent absence of calls, Ø2 and Ø6 will gap out and other phases can be serviced when a demand exists. Queues might form on the approaches served by Ø2 and Ø6 while the other phases operate, but these will be recognized by DARTS and projected to adjacent downstream intersections for platoon progression consideration.

When the interval set on timer T 1 has expired, timer T 2 is started. During the interval timed by T 2, DARTS checks the status of the downstream controller and, if necessary, sends one of two commands to the controller to assure progression for the approaching platoon. The interval timed by T 2 should begin when the approaching platoon is at a position beyond which there is inadequate time to terminate Ø6, provide Ø6 change interval, service the longer of Ø4 or Ø5 with minimum green, provide the associated Ø4 or Ø5 change interval and return to Ø6 and allow for driver perception-reaction time before the platoon would arrive at the downstream Ø6 detectors. The interval should end either when the platoon would arrive at the outermost Ø6 detector or when the platoon would be at a location which would allow for the longer minimum green of Ø4 or Ø5 plus an appropriate change interval and display of Ø6 green plus driver perception-reaction time before arrival of the platoon at the downstream intersection, whichever is earlier. If the controller is in Ø6 green at the beginning of the T 2 interval, DARTS places a continuous call on Ø6 to extend the green throughout the T 2 timed interval. If at the beginning of the T 2 interval the controller is in Ø4 beyond the minimum green and a Ø5 call is present, DARTS will force the controller to terminate Ø4 and immediately service Ø5. If at the beginning of the T 2 interval the controller is in Ø4 minimum green or in Ø5, DARTS sends no command to the controller. When the interval set on T 2 has expired, timer T 3 is started.

At the beginning of the T 3 timed interval, DARTS sends continuous phase-omit and force-off commands to all phases which conflict with Ø6. This interval should be set as the longer of the minimum green plus the associated change interval for Ø4 or Ø5 plus driver perception-reaction time. DARTS provides an alternative platoon identification feature for a moving platoon that approaches the downstream intersection during the T 3 interval. If T 3 is timing, Ø6 detectors are being actuated, and Ø6 green is displayed (see CARRYOVER, Fig 1), the DARTS at Cross Street B sends a platoon identified message to the DARTS at the next adjacent downstream intersection. This starts the platoon progression sequence in the DARTS at the next intersection and confirms the fact that a platoon actually exists at the local intersection (Cross Street B, Fig 1). If the approaching platoon does not arrive over the Ø6 detectors during the T 3 interval, Ø6 green will be displayed as a result of the DARTS commands issued to conflicting phases during the T 3 interval, but the platoon progression sequence in the DARTS at the next intersection will not be initiated by the carryover feature of the local DARTS. Thus, false triggering of the progression sequence at the next intersection is prevented if the progressing platoon breaks up or is delayed, but smooth, coordinated flow is provided when a platoon actually progresses as expected. When the T 3 interval has expired, DARTS returns the controller to normal operation with local detection.

Conflicting Phase Evaluation

The previously described timing functions of DARTS, which provide progression for platoons of traffic on the main street, if utilized alone can possibly affect local actuated controller operations to the extent that traffic on conflicting phases will experience intolerable delays and excessive queue buildup. To prevent such situations from developing, DARTS includes a series of timers which monitor the time that detectors on the approaches that are served by the conflicting phases are occupied. On each conflicting phase, one time-waiting timer (e.g., TW 1, Fig 1) is connected to a presence detector near the intersection, and a queue-length timer (e.g., QT 1, Fig 1) is connected to another presence detector that is set back from the intersection far enough to identify an excessively long queue on that approach. The series of timers are designated as TW 1, QT 1, TW 2, and QT 2 in Fig 1. Timers TW 1 and QT 1 monitor Ø5 left-turn approach, and TW 2 and QT 2 monitor the Ø4 cross approaches.

If the detector/s to which any of these timers is connected is continuously occupied longer than the interval set on the timer, DARTS commands to the phase associated with the monitoring detector/s is inhibited and the Ø2 and Ø6 detectors are also temporarily disabled. The controller is thus allowed to extend the green on the excessively-affected phase/s up to the maximum extension for that phase. When the penalized phase has been serviced, DARTS commands to the phase are resumed. Each timer is reset whenever the detector to which it is connected is not occupied.

To provide progression for platoons of traffic in the opposing direction, all DARTS functions described above and shown in Fig 1 must be duplicated. Commercial versions of the DARTS which incorporate the features discussed in this chapter provide for two complete sets of hardware to be mounted in a single compact cabinet.

Specifications for DARTS

A specification for an expanded version of DARTS was prepared by the Texas State Department of Highways and Public Transportation in the summer of 1981. A copy of this specification is included in the report as Appendix A for convenience of the reader. The specification incorporates the features discussed in this chapter plus several additional controller supervisory functions that increase the flexibility of application including the handling of pedestrian-actuated phases.

CHAPTER 3. STUDY SITES

Evaluation of DARTS necessitated the collection of field survey data to provide measures of effectiveness. In the early stages of development, two pilot model DARTS units were installed at a site on Pat Booker Road (SH 218) in the northeastern San Antonio metropolitan area for observation under traffic.

Pat Booker Road Site

Pat Booker Road (SH 218), located in Universal City, was selected by District 15 personnel for studying the viability of DARTS. The section of Pat Booker Road that was used in the study was located between Loop 1604 interchange and Coronado intersection and was approximately 0.9 mile in length (see Fig 2). The roadway was four-lane and was intersected by two-lane local streets which served the adjacent residential developments along the highway.

At the time that the pilot model DARTS units were first installed, this stretch of Pat Booker Road carried heavy directional traffic volumes during both the morning and evening peak periods. The major traffic generator was Randolph Air Force Base located about two miles east of the study site. The main entrance was linked to Interstate Highway 35 by Pat Booker Road and a large percentage of the traffic to and from the base traveled this convenient east-west route.

Just before the field traffic survey was conducted at the site in December 1977, a new section of C. W. Anderson Loop (Loop 1604) was opened and a major portion of the Randolph Air Force Base traffic was attracted away from Pat Booker Road. Traffic through the DARTS test section during the first evaluation survey was far too light to demonstrate the capabilities of the system. The decision was made to select a new DARTS evaluation site where traffic patterns would warrant progression during peak hours and normal actuated control during off-peak periods. The rather simple pilot models of DARTS (three timers for Main Street traffic only) were later removed from the Pat Booker Road site.

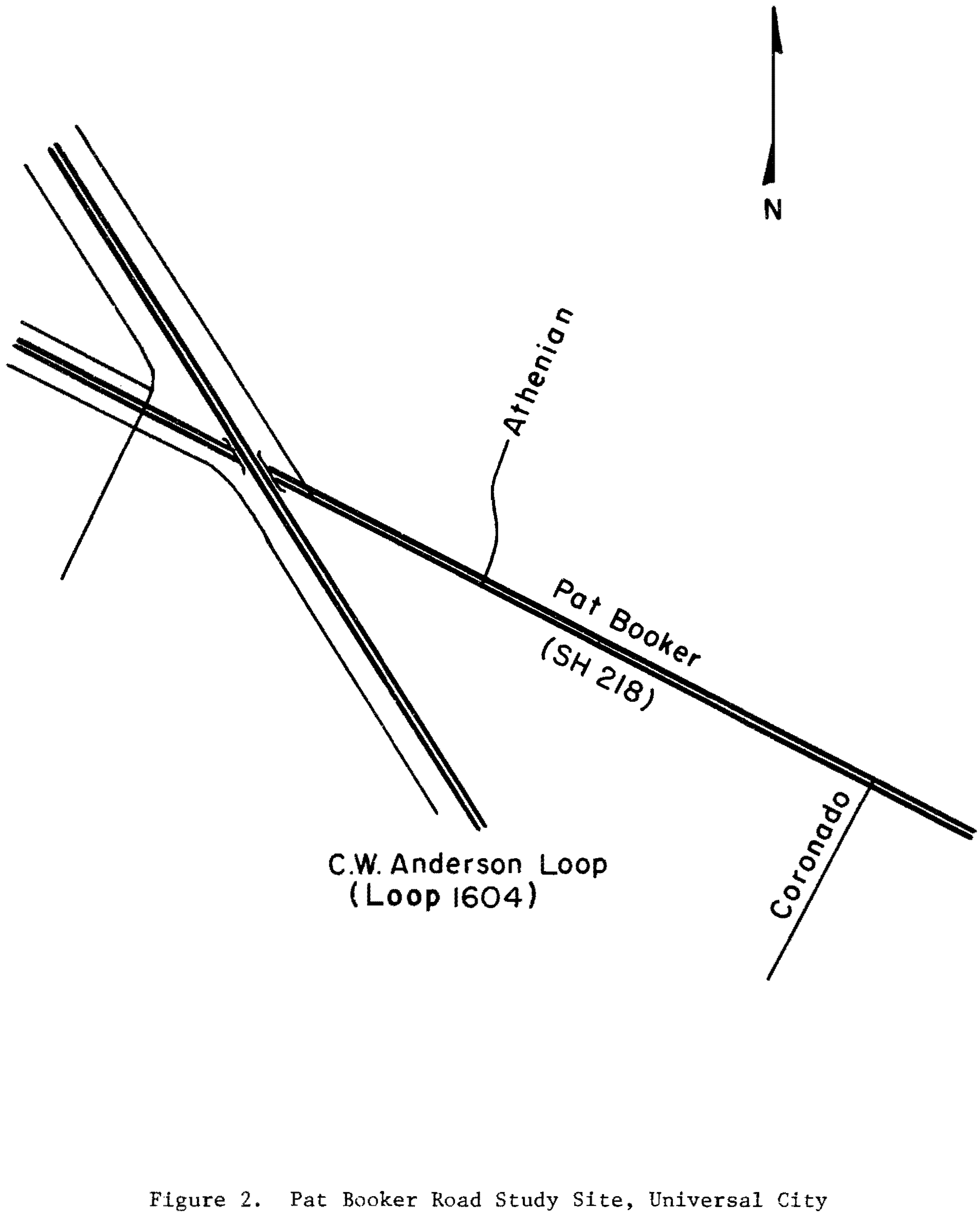


Figure 2. Pat Booker Road Study Site, Universal City

Bandera Road Site

Personnel from District 15, State Department of Highways and Public Transportation, suggested in February 1978 that a section of Bandera Road (SH 16) through Leon Valley in the northwestern part of the San Antonio metropolitan area be utilized as the new DARTS study site. This section was undergoing traffic control improvements at the time and had the type of directional traffic patterns which could justify progression through a series of intersections during peak periods. Off-peak traffic patterns along the route and on the cross streets were highly variable and warranted traffic-actuated control at the individual intersections.

Figure 3 shows the Bandera Road study site which runs northwesterly approximately two miles from the diamond interchange at Interstate Loop 410. Bandera Road is a four-lane divided highway that is intersected in this distance by a number of collector streets and a farm-to-market highway (FM 471). Land use along most of the section is residential development, but considerable commercial activity fronts on the highway near the southeast end of the study site. Traffic volumes are high along Bandera Road during both morning and evening peak periods.

DARTS units were installed along Bandera Road at four intersections: Wurzbach Road, Seneca Drive, Grissom (FM 471), and Huebner Road as indicated in Fig 3. This work was completed in April 1978. Spacing between these intersections is approximately as shown below:

Wurzbach Road		
		3,600 feet
Seneca Drive		
		2,335 feet
Grissom (FM 471)		
		2,280 feet
Huebner Road		
Total Section	=	8,215 feet = 1.56 miles

Separate left-turn lanes with detectors were provided on Bandera Road at each of the signalized intersections, and full-actuated NEMA standard controllers were used. Timing of the controllers was set by District 15 personnel.

The DARTS units were second-generation equipment built in the District 15 signal shops. Each unit included seven timers. Four of these (Platoon Timer, T 1, T 2, and T 3) were as described in Chapter 2 and served to identify a

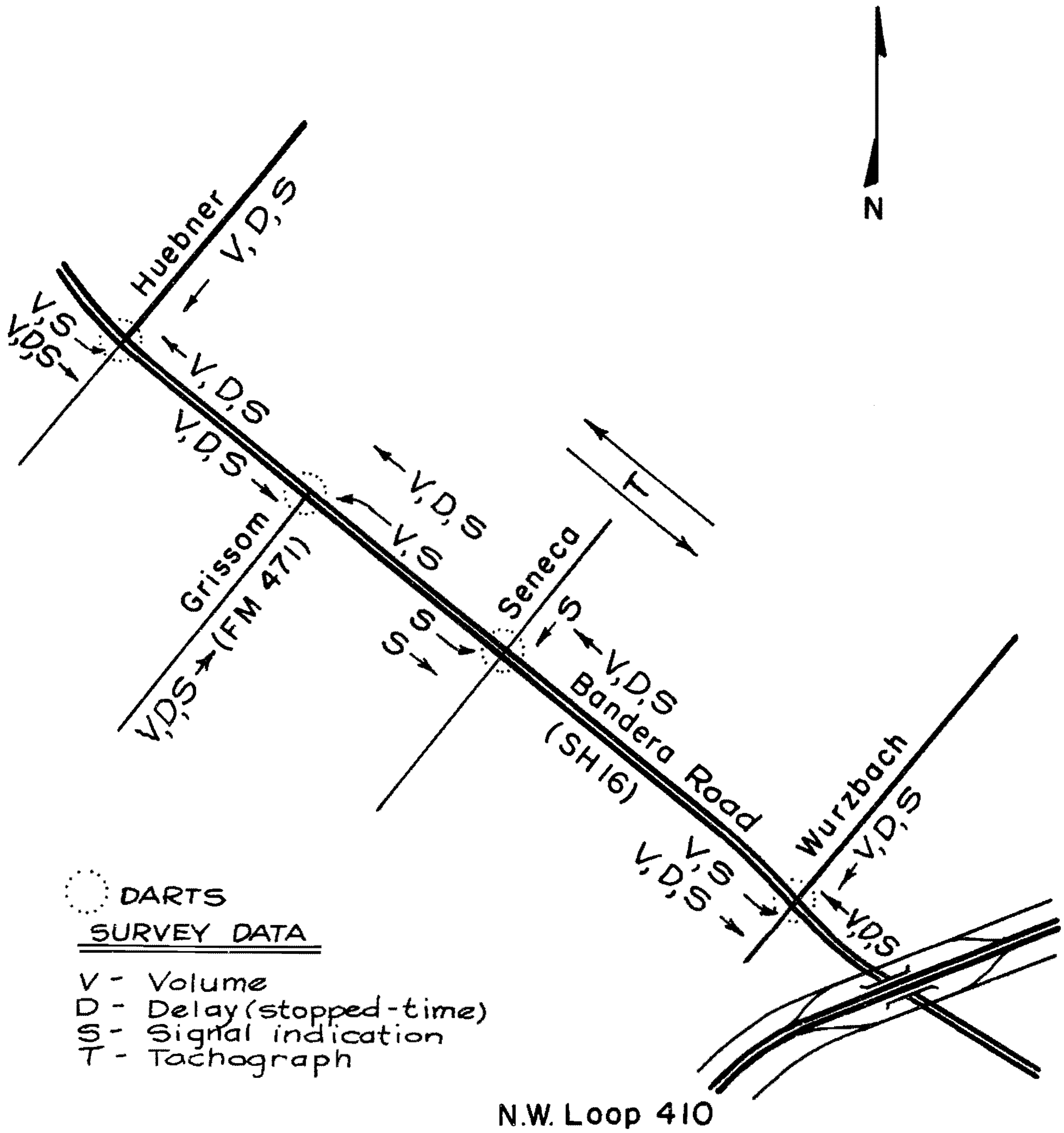


Figure 3. Bandera Road Study Site

platoon of vehicles going in one direction on Bandera Road and project its position in time to the next downstream intersection. The remaining three timers monitored the time waiting for traffic over the detectors on the cross street and in the left-turn lanes on Bandera Road. Any of these three timers could activate control logic which would interrupt DARTS commands for progression on Bandera Road when traffic serviced by conflicting signal phases was being penalized excessively. Some of the DARTS features that are described in Chapter 2 (see also Fig 1) were not yet implemented in this generation of equipment.

A number of traffic performance parameters can possibly serve as measures of effectiveness for a control system. The survey data that were taken for this purpose at the Bandera Road study site are indicated in Fig 3 and discussed in detail in Chapter 4. It was not considered feasible, nor necessary, to measure all parameters at every intersection where a DARTS unit was installed.

CHAPTER 4. STUDY METHODOLOGY AND EQUIPMENT

The primary function of DARTS, as described in Chapter 2, is to coordinate the timing of a series of actuated signal controllers that are installed at adjacent intersections along an arterial street or highway in such a way that platoons of traffic can move smoothly through the series of intersections without excessive stopping or delay. In order to evaluate the effectiveness of the system in providing this function, it was necessary to make field measurements of delay to traffic using the arterial under various representative traffic and traffic control conditions. Three conditions needed to be evaluated: (1) DARTS units off, i.e. no external supervision of the individual local actuated signal controllers; (2) DARTS units operational for one direction of progression only, e.g. outbound direction; and (3) DARTS units operational simultaneously for both directions of progression along the arterial. Delay measurements for these conditions could be compared only under similar traffic volume conditions; therefore, it was important to make field observations at times when volumes were known to follow a predictable and repeatable pattern.

Other indicators of the effectiveness of the DARTS in satisfying its primary function were the number of stops and the speed attained by traffic on the arterial. Again, these parameters would need to be measured under representative traffic volume conditions.

If it could be shown that DARTS reduced delay and number of stops for traffic on the arterial and that speed also increased, the system could be judged successful in satisfying its primary purpose. One or more of these parameters could serve as a basis for judgment, but quantitative measurements of each were required in any event.

Another concern about the effectiveness of DARTS stemmed from experience with an early version of the equipment which provided for platoon progression but made no provisions for evaluating the effects on traffic using conflicting signal phases. It was therefore deemed desirable to make field measurements of delay experienced by traffic on conflicting phases under various DARTS operational conditions.

Likewise, questions still existed as to whether the DARTS should be used for only one direction of progression at a time. That is, could there be adverse interaction between two systems used simultaneously to provide progression in opposite directions along an arterial? Field measurements of the parameters mentioned above would quantify these effects.

Figure 3 shows the parameters that were actually measured in the field studies conducted on Bandera Road. Conduct of the surveys is discussed further in the next chapter.

The basic design for the traffic data recording equipment that was used in the field studies was developed at the Center for Highway Research under a previous research study No. 3-18-72-184 and is described in Ref 2. Each device provided for recording two channels of digital information. Because of the large number of parameters to be observed in this study, it was necessary to construct additional units. A total of ten units were utilized to record traffic volume, stopped time delay, and signal indications against a 1-second incremented time base. These unique portable recorders with a synchronized time base made it possible to relate observations made at the various locations along the study section to each other in a meaningful way.

Tachograph runs through the system were made by District 15 personnel in order to sample speeds and number of stops on the arterial for each of the DARTS operating conditions. Volume count data from recording mechanical counters along the periphery of the study area were also provided by these personnel.

CHAPTER 5. BANDERA ROAD STUDIES

The field study site for evaluating the DARTS unit was moved from Pat Booker Road to Bandera Road in late spring of 1978. Plans of the Bandera Road site were furnished by District 15 of the State Department of Highways and Public Transportation and a series of hourly traffic volume counts were conducted at the site by District personnel to identify the prevailing traffic patterns at the site. Traffic volume and delay recording equipment was constructed by University personnel for use in the field studies.

A preliminary field survey of the Bandera Road site traffic volumes was conducted in June 1978. Counts were made by manual observation and recorded on the portable recorder against a 1-second time base. The traffic volume data obtained from this preliminary study were analyzed with regard to the location and magnitude of the vehicular flows. Since no delay data were recorded, the traffic movements with the greatest potential for causing delay were identified conceptually.

The preliminary field study established a hierarchial system for the allocation of available delay recording equipment for future field studies. Equipment was allocated in the following order:

(1) A minimum of one recorder was required at each intersection for the measurement of the progressive vehicular movement and signal timing.

(2) Subsequent allocations of delay recorders were based on the importance of the movement to be observed, hence:

  (a) side street volume and delay,
  (b) inbound street volume and delay, and
  (c) left-turn volume and delay.

(3) The above allocations were also modified due to the relative importance of a particular traffic movement between all the intersections in the system.

This hierarchy was adhered to throughout the rest of the studies in both summer and fall.

Tachograph

The tachograph is a device that records the time space history of a vehicle traveling a specific route. The tachograph is mounted inside a test vehicle and is connected to the vehicle's odometer mechanism, from which is obtained the distance the vehicle travels. Distance is recorded on a piece of graph paper (circular or strip) which is advanced at a specified time rate. The average speed is determined by dividing a selected distance traveled by the time required to transit the distance.

There are two basic ways to employ the tachograph in the measurement of average speed: the floating-car technique and the maximum-car technique. In the floating-car technique the vehicle operator tries to pass as many vehicles as pass the test vehicle and thereby maintain a constant relative position in the traffic stream. The maximum-car technique, however, allows the driver to drive in a manner that allows maximizing the test vehicle's movement. In this case, the driver tries to operate as closely to the posted speed limit as is safely possible. For the purposes of this study, the maximum-car technique was utilized.

The tachograph was operated by a District 15 driver during all the volume delay studies at the Bandera Road site. In most cases, seven tachograph runs were made by the test vehicle in both the outbound and inbound directions. The few times that the tachograph did not perform seven test runs in each direction was the result of weather conditions such as rain.

Mechanical Volume Counters

In order to verify the volume counts recorded on the portable volume-delay recorders, a backup system was needed against which to check the recorder-derived volumes.

District 15 provided six pneumatically activated mechanical volume counters which were deployed in the study area. The pneumatic detectors were situated at three stations on Bandera Road. One count station was located at each end of the study control area. These two stations monitored the vehicular flows in and out of the study area. The third station was situated inside the DARTS control area between the Seneca and Grissom intersections with Bandera Road. At all three stations, the traffic volumes were measured in both the outbound and inbound directions.

Summer Field Studies

It was decided after the June 1978 traffic volume study that a single day would be used for a full field study of the DARTS unit operation. The schedule drawn up for the field study provided for both morning and evening observations of peak hour traffic loading of the DARTS system. Each peak volume traffic period was identified from 24-hour traffic volume counts obtained from District 15. The methodology developed for evaluation of the DARTS outlined the need for the Bandera Road network to be studied with the DARTS in "on" and "off" modes of operation. The reason for the need to observe the traffic network without benefit of DARTS operation was to establish a base or zero case with which to compare DARTS operation. In order that similar "on" and "off" DARTS operational cases be obtained from the same peak traffic period (morning or evening), it was decided that each peak period should be divided into two equal study parts. In essence, data from the Bandera Road network was recorded with the DARTS operations up to the attainment of peak traffic flow. Once peak traffic flow was obtained, the DARTS was shut down and the system allowed to operate in an "off" mode operation. This procedure was followed in both the morning and evening studies.

Fall Field Sites

The evaluation of the data obtained from the June 1978 field studies showed that the short-time fluctuations in traffic volumes during the peak hours made it impossible to identify any effects which DARTS might have on delay and travel speed through the section. The fall field study was therefore scheduled so that three different modes of DARTS operation could be observed for a longer period of time. These modes were: (1) DARTS off, (2) outbound DARTS on, and (3) outbound and inbound DARTS on. Each of the modes was studied for a three-hour period (3:30-6:30 p.m.) on a Wednesday (1 Nov. 78, 8 Nov. 78, and 29 Nov. 78) in November 1978. This schedule produced stable and consistent traffic patterns which were used to collect quantitative data upon which to base a comparison of the effects of the various DARTS operational modes. The results of the data analysis are presented in the next chapter.

CHAPTER 6. EVALUATION AND CONCLUSIONS

Data from the DARTS evaluation field studies on Bandera Road are summarized in tabular form in Appendix B and in graphical form in Figs 4-6. Observations of traffic behavior were made at four signalized intersections along a 1.56-mile section of this highway for approximately three hours on each of three Wednesday afternoons in November 1978. For reference, one survey period was devoted to measurement of volume, delay, speed, and number of stops when each signal controller operated in its normal full-actuated mode without any DARTS influence - all DARTS units were switched off during this period. A second 3-hour observation period involved similar measurements when the DARTS units which provided platoon progression coordination in the outbound (heavy traffic) direction were activated. The third study period had the DARTS units for both outbound and inbound progression switched on at the same time.

The traffic volumes through the study area were quite consistent for each of the survey periods as shown by the graphs at the top of Figs 4 and 5. The outbound traffic when all DARTS units were off was about 5 percent higher than on the other two days, but all other volumes were remarkably uniform. Outbound volumes were generally about twice the inbound volumes on Bandera Road. Cross-street and left-turn volumes were very consistent throughout the study.

Stopped-time delay is one quantifiable measure of effectiveness for traffic control systems. Total stopped-time delay for the various control modes is shown in the center graphs of Fig 4, and average stopped-time delay per vehicle is shown at the bottom. Little difference in delay was observed for the three DARTS modes except for traffic at the Wurzbach Road intersection. On the day when the outbound DARTS system was operating, delays to outbound (NW) traffic on Bandera and to traffic (SW) on Wurzbach were considerably higher than on the other two days. Examination of the recorded signal indication data revealed an apparent malfunction in the inbound left-turn Ø5 detector at Wurzbach which caused the controller to max-out on this

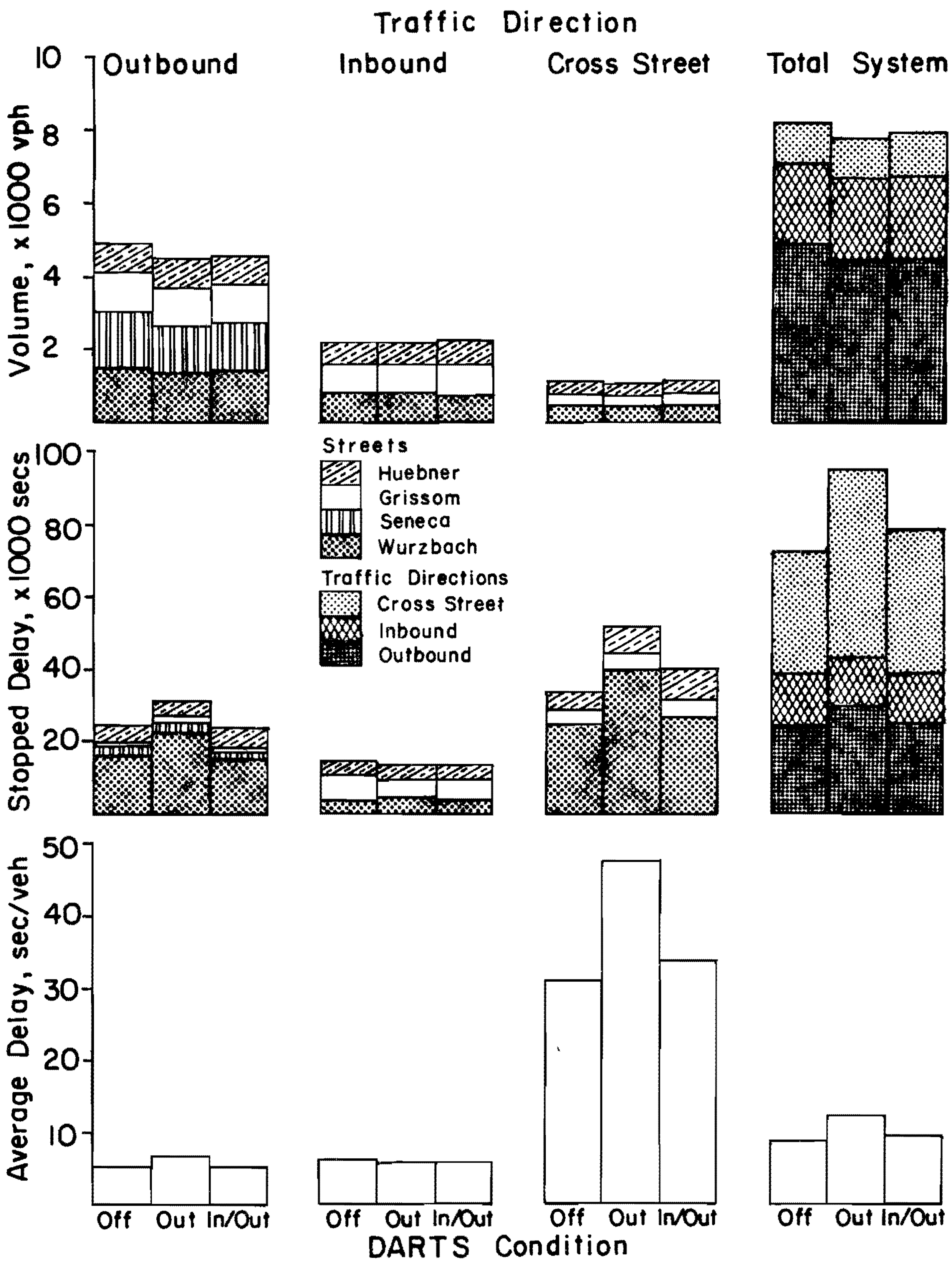


Figure 4. Summary of volume and delay data from the Bandera Road Study

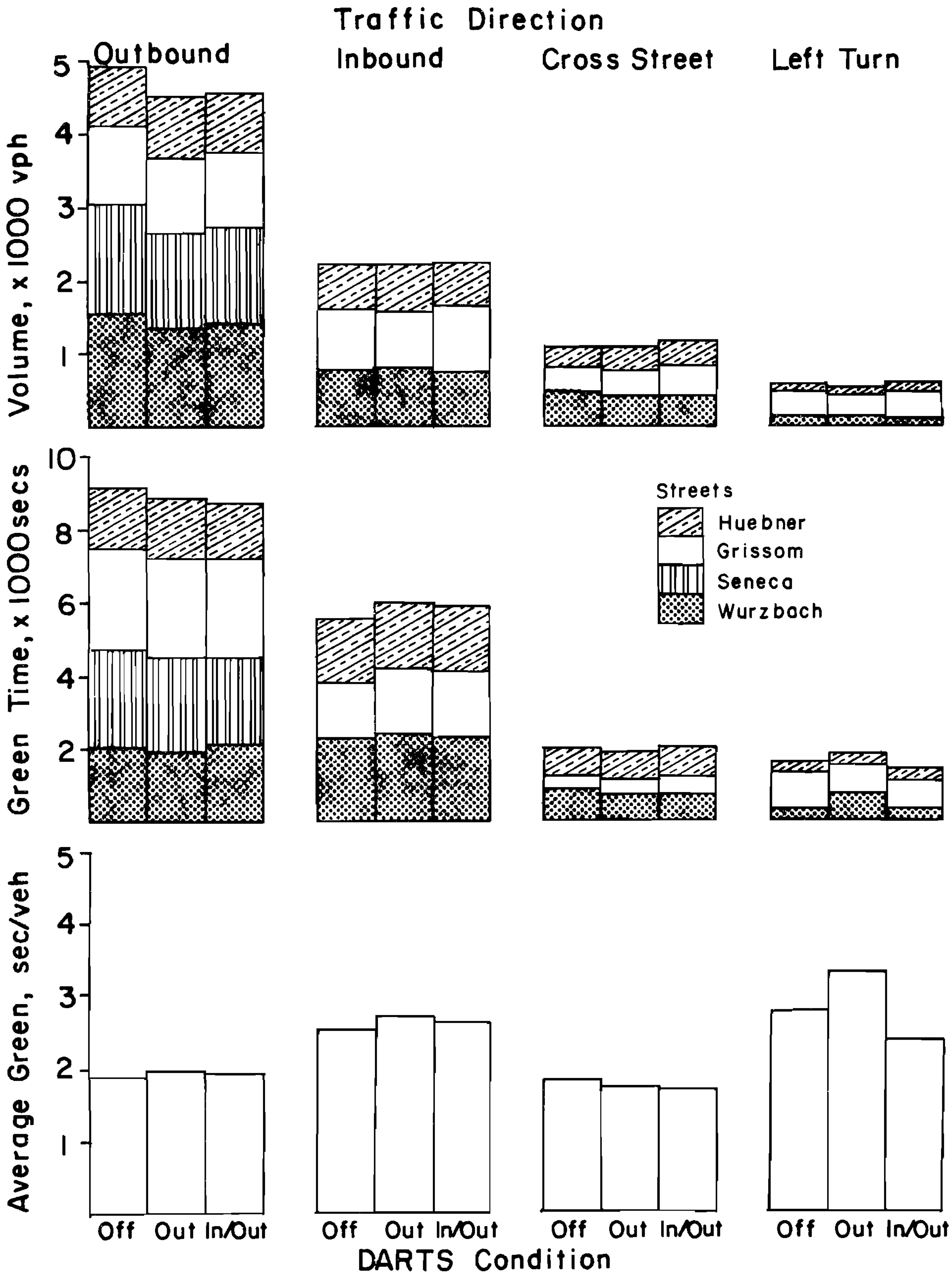


Figure 5. Summary of volume and signal performance data from the Bandera Road Study

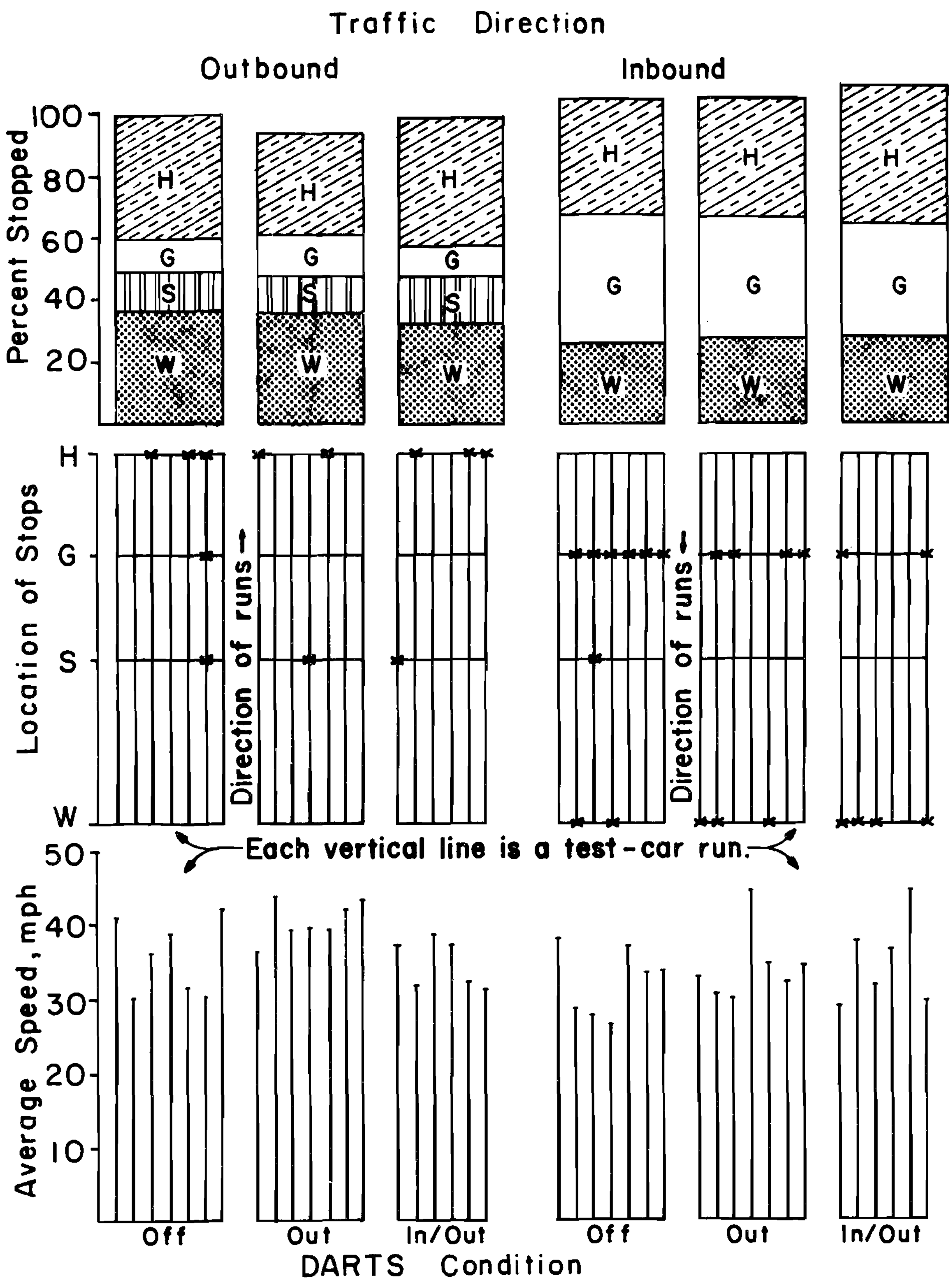


Figure 6. Summary of data from Tachograph runs on Bandera Road and from delay recording

phase throughout most of the study period. Further evidence of this is shown in Fig 5. The higher delay to traffic on phases that conflicted with this left-turn phase can probably be attributed to the hung detector.

Another measure of effectiveness for DARTS in providing platoon progression along the artery is the percent of vehicles that are required to stop. Percentages of stops for inbound and outbound traffic determined from the volume and delay recordings are shown in the upper part of Fig 6. The percentages were calculated as the ratio of the number of stops at each individual intersection to the number of vehicles entering that intersection from Bandera Road. All traffic on the artery did not travel through the entire test section; therefore, the cumulative percentages of stops do not always total exactly 100 percent. The scale provides a convenient means for reading relative proportions of stops observed at each individual intersection under various control conditions. Except for about a 5 percent reduction in percent stops at the Huebner Road intersection when the outbound DARTS was operating, the other percentages are quite consistent. The DARTS seemed to have no pronounced effect on the percentage of vehicles required to stop.

Further data concerning stops in the study section are shown in the middle graphs in Fig 6. The stops experienced in each tachograph run are marked along the vertical lines at the various intersections. In the outbound direction, the fewest stops (three in seven runs) occurred when the outbound DARTS was operating. When both DARTS directions were on, four stops were made in six runs. When DARTS was off, five stops were required in seven outbound runs; three of these were on one run. In the inbound direction, the fewest stops (six in six runs) occurred when both DARTS directions were operating. With DARTS off, the test car stopped at Grissom Road on six of seven runs.

A Chi-square statistical test on these data indicates that the observed differences in the number of stops made by the test car would be expected due to chance happening alone 90 times out of 100. Therefore, it appears from these test car runs that the DARTS system had no significant effect on the number of stops for traffic on Bandera Road during the study.

Average speed through the system is an indicator of effectiveness in providing progression. Speed data from the tachograph runs are shown at the bottom of Fig 6. Even though the data are highly variable, speed in the outbound direction when the outbound DARTS was on averaged about 3 to 5 mph higher over the test section than for the other DARTS conditions.

Conclusions

The field study of DARTS operations on Bandera Road in the fall of 1978 indicated that the system had no pronounced effect on delay, number of stops, or percent of vehicles stopped on the artery either when DARTS was operated in one direction alone or when both directions were operated at the same time. A very slight reduction in percent of outbound vehicles stopped was observed when the outbound DARTS was operated alone. Likewise, there was about a 3 to 5 mph speed increase for this same operational situation. These changes are not of sufficient magnitude to say that DARTS was highly effective in improving traffic flow on Bandera Road during the study.

When the conflicting phase time-waiting monitors were operating in DARTS, the delays to cross street traffic were not found to be excessive when the system was providing platoon progression on the artery even though they were slightly higher than when DARTS was not operating. The version of DARTS that was used during the study did not include queue timers as more recent versions do.

The effectiveness of DARTS probably depends to a considerable degree upon the accuracy with which the various timers are set to reflect traffic conditions on the artery. Experience in adjusting the settings will no doubt improve the overall effectiveness of the system. The potential for the system as an inexpensive means of providing coordination for a series of actuated controllers is considerable and further application of the system in appropriate situations is encouraged.

Postscript

Since completion of this study, two more DARTS systems have been installed in Texas [Ref 3]. One of these involves 12 full-actuated signalized intersections in District 15 (San Antonio) on a 3.4-mile section of SH 218 (23,000 vpd) in Universal City at the initial study site described in Chapter 3 as the Pat Booker Road Site. The other system [Refs 3 and 4] includes four closely-spaced signalized intersections on Ocean Drive (35,000 vpd) in Corpus Christi (District 16).

Travel time runs through the SH 218 DARTS system [Ref 3] indicate that "the average speed for peak and off peak traffic has increased from 29 mph to 34 mph and that the number of stops has been reduced from an average of 3.9 to 0.8 in each direction. During the off peak periods, the average speed increased from 29 mph to 35 mph with a reduction of stops from 4.0 to 0.7. The average of the posted speed limits along SH 218 is 39 mph." The intersections operated under isolated full-actuated control before the DARTS system was installed at a cost of $150,000.

The DARTS system in Corpus Christi was installed in 1980-81 to replace an existing coordinated (pretimed) control system which used a long background cycle during the afternoon peak traffic period [Ref 4]. Significant benefits reported after "months of fine-tuning by personnel of the City and State Department of Highways and Public Transportation, District 15 personnel" include: 28 percent decrease in number of stops per day, 25 percent decrease in travel time, 42 percent decrease in passenger delay, 76 percent increase in average vehicular speed during peak hour traffic, 38 percent increase in average speed during non-peak periods, and a 37 percent decrease in gasoline consumption. This system includes both time-waiting and queue-length detectors on the cross streets and queue-length detectors at mid-block on the artery.

REFERENCES

1. NEMA Standards Publication for Traffic Control Systems/No. TS 1-1976, National Electrical Manufacturers Association, 155 East 44th Street, New York, N.Y., 10017.

2. "The Texas Model for Intersection Traffic-Development," Clyde E. Lee, Thomas W. Rioux, and Charlie R. Copeland, Research Report 184-1, Center for Highway Research, The University of Texas at Austin, December 1977, pp, 255-265.

3. "Texas Stand Alone Arterial Systems," presentation at Transportation Research Board Annual Meeting, January, 1981, by Herman E. Haenel and (updated) at Georgia Section Meeting of the Institute of Transportation Engineers, June, 1981, by Jim Williams. Copy made available by Texas State Department of Highways and Public Transportation, D-18T, Austin, Texas.

4. "Final Report, Traffic Signal Demonstration Program, Project TCD 1 (3), Corpus Christi, Texas," submitted March 8, 1982, to Texas State Department of Highways and Public Transporation, D-18T by District 16 (Corpus Christi). Copy made available by Texas State Department of Highways and Public Transportation, D-18, Austin, Texas.

APPENDIX A

APPENDIX A

Division of Safety and
Maintenance Operations

Traffic Engineering
Section

TEXAS
STATE DEPARTMENT OF HIGHWAYS
AND PUBLIC TRANSPORTATION
SPECIFICATION
FOR

DYNAMIC ARTERIAL-RESPONSIVE TRAFFIC SYSTEM
(DARTS)

1.0 SCOPE

The intent of this specification is to describe a dynamic system of full-traffic actuated controllers being coordinated on an intersection to intersection basis by maintaining a progression point for the start of artery green, the length of which shall be determined solely by the traffic signal controller in the normal vehicle passage extension manner. Thus, there will be no fixed progression bandwidth or background cycle length, with the start of artery green being established in terms of artery platoon arrival information and the termination of green taking place by gap-out or max-out in accordance with standard practice.

2.0 METHOD OF ACHIEVEMENT

To carry out this process, each intersection is equipped with a solid state digital Dynamic Coordination Unit (DARTS unit) which shall have two main functions: (1) to determine the presence of a platoon from either direction and thereby send signals downstream to adjacent controllers when such a determination is made, and (2) to receive information from upstream controller coordination units of the approach of a platoon and proceed to clear its conflicting phases as necessary to provide the arriving platoon a green signal. When traffic on a conflicting phase reaches excessive stacking or time-waiting values, the logic shall be designed to inhibit the artery progression until that phase has been serviced.

3.0 FUNCTIONAL REQUIREMENTS

3.1 The DARTS unit at each intersection shall be capable of transmitting and receiving various messages, to and from other controllers' DARTS units. The message received shall be used to start various time intervals, which in turn shall be used to guide intersection controllers to provide arterial progression. Each Dynamic Coordination Unit shall provide for transmitting, receiving, buffering and interconnecting line isolation.

3.2 Each DARTS unit shall generate and receive the following messages and then respond to these messages as explained below. The Inbound Platoon Start (IPS) signal (Phase 2) is generated and sent to the next intersection when:

(1) the inbound artery detector has caused the inbound platoon recognition timer to time out; and

(2) the inbound artery signal is green; and

(3) the following six sequential intervals, T-1, T-2, T-3, T-4, T-5, and T-6 at this intersection are inactive.

Each time the IPS signal is generated, an output is transmitted on both the Primary and Alternate Platoon Start interconnect line pairs.

3.3 The following sequence of intervals is initiated when an IPS signal is received at an intersection equipped with a DARTS unit. Each interval shall provide the following outputs, some of which shall be switch programmable:

T-1 - During this interval the outputs from Phase 2 and Phase 6 detectors are disabled. A switch-programmable option shall be provided to omit pedestrian service in Phases 3, 4, 7, and 8 during this interval.

T-2 - At the start of this interval, a switch-programmable option shall impose a signal of 500 ms in length upon Ring 1 Force Off if Phase 3 is green and Phase 4 is being called. This programmable option shall also impose a signal of 500 ms in length on Ring 2 Force Off if Phase 7 is green and Phase 8 is being called. A second switch-programmable option shall impose a Pedestrian Omit signal to Phases 3, 4, 7, and 8 during this entire interval.

T-3 - At the start of this interval, a switch-programmable option shall impose a signal of 500 ms in length upon Rings 1 and 2 Force Off if Phase 4 and Phase 8 are green and Phase 1 is being called. A second switch-programmable option called Static Platoon shall be provided to:

1. Omit Phases 1, 3, 4, 7, and 8; and

2. Apply Force Off to Ring 1 and 2 if Phases 3, 4, 7, or 8 are green; and

3. Apply Force Off to Ring 1 if Phase 1 is green; and

4. Send an IPS signal to the next inbound intersection if this intersection is in Phase 2 green or flash and has a Phase 2 detection; and

5. Call Phase 2 at this intersection.

Pedestrian service to Phases 3, 4, 7, and 8 shall be omitted during this interval.

T-4 - This is a separate interval with the same features as T-3 with separate switches as defined in T-3 for this interval.

Pedestrian service to Phases 3, 4, 7, and 8 shall be omitted during this interval.

T-5 - This interval has the same features as Interval T-3 with the Static Platoon switch active. These features shall be present in every Inbound T-5 interval.

Pedestrian service to Phases 3, 4, 7, and 8 shall be omitted during this interval.

T-6 - A switch-programmable option shall send an IPS signal to the next inbound intersection if this intersection is in green or flash and has a Phase 2 detection.

Pedestrian service to Phases 3, 4, 7, and 8 shall be omitted during this interval.

3.4 A switch-programmable option shall be provided during all of the above intervals that will:

1. Hold Phase 4 and Phase 8 if Phase 1 does not have a call; and

2. Hold Phase 1

3.5 Another switch-programmable option shall be provided to impose the above signals to the unit when the next inbound, downstream interconnection is in its intervals T-1, T-2, T-3, T-4, T-5, or T-6.

3.6 All functions defined for the inbound requirements above shall be duplicated for the outbound progression requirements. All references to inbound become outbound and all timers and timed intervals are provided independently for outbound use only. The references to the phases are mirrored (i.e., Phase 2 = Phase 6, 6 = 12, 1 = 5, 5 = 1, 3 = 7, 7 = 3, 4 = 8, 8 = 4).

3.7 When a Primary Platoon Start Signal is received, the DARTS unit shall immediately advance to Interval T-1 and begin timing the primary time set. It shall then advance sequentially through T-2, T-3, T-4, T-5, and T-6, stopping at each interval for the duration of time programmed in the primary time set. Platoon Start Signals for either primary or alternate time sets which may arrive during any of these intervals, will have no further affect on the sequence or timing.

When an Alternate Platoon Start Signal is received, the DARTS unit shall immediately advance to Interval T-1 and begin timing the alternate time set. It shall then advance sequentially, through T-2, T-3, T-4, T-5, and T-6, stopping at each interval for the duration of time programmed in the alternate time set. Platoon Start Signals for either primary or alternate time sets, which may arrive during any of these intervals, will have no further effect on the sequence or timing.

3.8 A separate Queue Timer and Time Waiting Timer shall be provided for each of Phases 1, 3, 4, 5, 7, and 8. Queue Timers will time when detection is recognized over the Queue Detectors of the appropriate phase. Time Waiting Timers will time when detection is recognized over the passage detector of the appropriate phase. These timers shall not time during the appropriate green. When the Timer(s) times out, as a result of continuous detection for the programmed time period, the DARTS commands which are in conflict with that phase shall be inhibited until that phase has terminated green. The detectors for phases 2 and 6 shall be disabled if either of these phases is green during the time-out condition.

3.9 A separate Pedestrian Time Waiting Timer shall be provided for each of phases 4 and 8. The timer(s) shall begin timing when a pedestrian call is received. The timer shall be reset each time the Walk Signal is terminated. Should either of these timers time out, all DARTS commands shall be inhibited until the appropriate WALK signal is serviced. Phases 2 and 6 detectors shall be disabled if either of these phases is green during the time-out condition.

3.10 There shall be provided an alternate set of time increments for both the inbound and outbound directions for T-1, T-2, T-3, T-4, T-5, and T-6. The alternate set of time increments shall be initiated by both of the following methods:

1. An Alternate Platoon Start Signal is received before a Primary Platoon Start Signal is received and T-1 through T-6 Intervals are not active.

AND

2. The Alternate Platoon Start Time Set is selected by time clock for either Primary or Alternate Platoon Start commands. When this time clock input is active, the alternate time set shall prevail for either Platoon Start Inputs.

3.11 When a remote Inbound or Outbound Disable is received at an intersection, this message shall regenerate that disable signal and transmit same to the next intersection. This feature shall permit either the inbound or outbound (or both) DARTS commands to be disabled for the system.

3.12 Removing the coordinating unit shall not affect the normal controller operation. No special jumpering shall be required to make the controller operational with respect to detector inputs. Therefore, it is recommended that detection inputs to the controller be disabled using external logic driven by the coordination unit.

3.13 Switches

All switch programmable options defined as functional outputs for T-1, T-2, T-3, T-4, and T-6 shall be provided in the form of DIP switches in the modules. There shall be a minimum of 20 switches per DARTS unit.

The following additional switches shall be provided on the face of the unit in the form of program pins, thumbwheel switches, or toggle switches or a combination thereof.

(1) Disable Phase 3 Queue and Time Waiting Output

This inhibits the output generated by a Phase 3 time waiting or queue time-out when switched on.

(2) Disable Phase 4 Queue and Time Waiting Output

This inhibits the output generated by a Phase 4 time waiting or queue time-out when switched on.

(3) Disable Phase 7 Queue and Time Waiting Output

This inhibits the output generated by a Phase 7 time waiting or queue time-out when switched on.

(4) Disable Phase 8 and Time Waiting Output

This inhibits the output generated by a Phase 8 time waiting or queue time-out when switched on.

(5) Disable Phase 1 Queue and Time Waiting Output

This inhibits the output generated by a Phase 1 time waiting or queue time-out when switched on.

(6) Disable Phase 5 Queue and Time Waiting Output

This inhibits the output generated by a Phase 5 time waiting or queue time-out when switched on.

(7) Disable Phase 4 Pedestrian Time Waiting Output

This inhibits the output generated by a Phase 4 ped. time waiting time-out when switched on.

(8) Disable Phase 8 Pedestrian Time Waiting

This inhibits the output generated by a Phase 8 ped. time waiting time-out when switched on.

(9) Disable Unit

This inhibits all DARTS commands when switched on, whether power is on or off.

(10) Lamp On-Off Test

This is a 3-position switch which will light all lamps when switched to "TEST"; will disable all lamps when switched to "OFF"; and will display active functions when switched to "ON".

(11) Power On-Off

This disconnects DC and AC supply voltage from DARTS unit when turned off.

(12) Stop Time

This inhibits all timing within the DARTS unit when switched on.

(13) Inbound Static Platoon Recognition Simulation

When this switch is on, an inbound platoon recognition timer time-out will activate the Phase 2 static platoon circuit.

(14) Outbound Static Platoon Recognition Simulation

When this switch is on, an outbound platoon recognition timer time-out will activate the Phase 6 static platoon circuit.

4.0 INTERFACE REQUIREMENTS

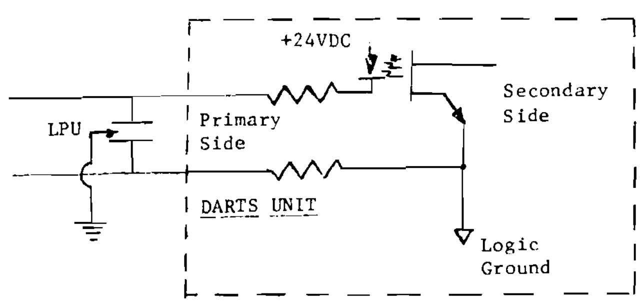
4.1 DC Power Supply

The DARTS unit shall be powered by the DC supply voltage supplied by the traffic controller with which it shall be used. The DARTS unit shall not draw more than approximately 300 ma current from this supply voltage. These DC supplies may range in levels of 15-30 volts DC, and may fluctuate as an unregulated source. A separate power supply to supply power to the indicator lamps shall be provided if necessary to meet the indicator brightness requirement. This shall have no affect, however, on the normal operation. When the controller unit power is shut down, the DARTS unit must shut down simultaneously.

4.2 Inputs

All inputs, with the exception of the optical isolated interconnect line circuits, shall be ground true and shall be active when pulled down to less than 1/3 of the normal pull-up voltage of 24 VDC. They shall then remain true until the pull-down is released and the pull-up voltage exceeds 2/3 of the normal 24 VDC. When the outputs from the controller which are used as inputs to the DARTS unit, such as Greens, Checks, etc., are activated or pulled down from their normal voltage of 24 VDC they shall draw between 0.4 ma and 1.0 ma, inclusive. Similarly, when the remote inputs, such as intersection detectors, queue detectors, etc., are activated or pulled down from their normal voltage of 24 VDC they shall draw between 2.0 ma and 3.0 ma, inclusive.

All inputs from interconnect line pairs shall be received through the use of optical isolators, and the local 24 VDC supply voltage.

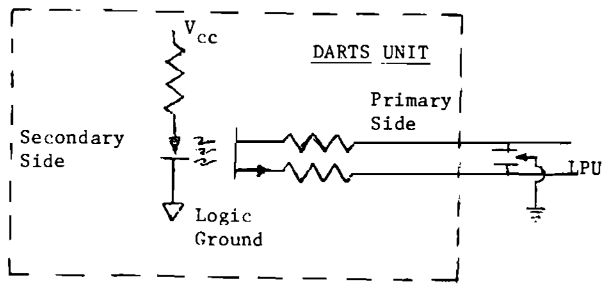


(one twisted pair of 24 AWG phone wire per message)

4.3 Outputs

All outputs with the exception of the optical isolated interconnect line circuits shall be ground true with a minimum current rating of 50 ma each at 30 VDC, and shall drive to within 2 VDC or less.

All outputs to interconnect line pairs shall be transmitted through the use of optical isolators, and the receiving intersection's 24 VDC supply voltage.



5.0 DESIGN REQUIREMENTS

5.1 Input/Output Requirements

The minimum input and output requirements for the DARTS unit shall be as follows:

Inputs

Pin No.	
1	120 Volts AC
2	Primary time set inbound platoon start (+)
3	Primary time set inbound platoon start (-)
4	Primary time set outbound platoon start (+)
5	Primary time set outbound platoon start (-)
6	Alternate time set inbound platoon start (+)
7	Alternate time set inbound platoon start (-)
8	Alternate time set outbound platoon start (+)
9	Alternate time set outbound platoon start (-)
10	Disable inbound coordination (+)
11	Disable inbound coordination (-)
12	Disable outbound coordination (+)
13	Disable outbound coordination (-)
14	T-1, T-2, T-3, T-4, T-5 OR T-6 ON Inbound Next Downstream Intersection (+)
15	T-1, T-2, T-3, T-4, T-5 OR T-6 ON Inbound Next Downstream Intersection (-)
16	T-1, T-2, T-3, T-4, T-5 OR T-6 ON Outbound Next Downstream Intersection (+)

Pin No. Cont.	
17	T-1, T-2, T-3, T-4, T-5 OR T-6 ON Outbound Next Downstream Intersection (-)
18	Inbound (Phase 2) static platoon detector
19	Outbound (Phase 6) static platoon detector
20	Inbound (Phase 2) detector
21	Outbound (Phase 6) detector
22	Unregulated or regulated supply voltage from local controller unit, of from 15 to 30 VDC to power the DARTS unit.
23	Logic ground from controller unit
24	Phase 3 detector
25	Phase 3 queue detector
26	Phase 4 detector
27	Phase 4 queue detector
28	Phase 7 detector
29	Phase 7 queue detector
30	Phase 8 detector
31	Phase 8 queue detector
32	Phase 1 detector
33	Phase 1 queue detector
34	Phase 5 detector
35	Phase 5 queue detector
36	Phase 1 green
37	Phase 2 green
38	Phase 3 green
39	Phase 4 green
40	Phase 5 green
41	Phase 6 green
42	Phase 7 green
43	Phase 8 green

Pin No. Cont.	
44	Phase 4 walk
45	Phase 8 walk
46	Phase 1 check
47	Phase 5 check
48	Phase 4 check
49	Phase 8 check
50	Stop timing
51	Disable indicator lamps
52	Key
53	Force to alternate time set (Inbound)
54	Force to alternate time set (Outbound)
55 thru 61	Spares
62	Chassis ground
63	AC common

Outputs (Amp 57 pin reverse connector #206438-1)

Pin No.	
1	Disable Phase 2 detector
2	Disable Phase 6 detector
3	Force Off Ring 1
4	Force Off Ring 2
5	Omit Phase 1
6	Omit Phase 3
7	Omit Phase 4
8	Omit Phase 5
9	Omit Phase 7
10	Omit Phase 8
11	Pedestrian Omit Phase 4

Pin No. Cont.	
12	Pedestrian Omit Phase 8
13	Phase 1 hold
14	Phase 5 hold
15	Phase 4 hold
16	Phase 8 hold
17	Phase 2 call (isolate from DARTS input, in cabinet)
18	Phase 6 call (isolate from DARTS input, in cabinet)
19	Inbound platoon start primary (+)
20	Inbound platoon start primary (-)
21	Inbound platoon start alternate (+)
22	Inbound platoon start alternate (-)
23	Outbound platoon start primary (+)
24	Outbound platoon start primary (-)
25	Outbound platoon start alternate (+)
26	Outbound platoon start alternate (-)
27	Inbound disable (+)
28	Inbound disable (-)
29	Outbound disable (+)
30	Outbound disable (-)
31	T-1, T-2, T-3, T-4, T-5 OR T-6 ON Inbound This Intersection (+)
32	T-1, T-2, T-3, T-4, T-5 OR T-6 ON Inbound This Intersection (-)
33	T-1, T-2, T-3, T-4, T-5 OR T-6 ON Outbound This Intersection (+)
34	T-1, T-2, T-3, T-4, T-5 OR T-6 ON Outbound This Intersection (-)
35	Inbound T-1 On
36	Inbound T-2 On

Pin No. Cont.	
37	Inbound T-3 On
38	Inbound T-4 On
39	Inbound T-5 On
40	Inbound T-6 On
41	Outbound T-1 On
42	Outbound T-2 On
43	Outbound T-3 On
44	Outbound T-4 On
45	Outbound T-5 On
46	Outbound T-6 On
47 thru 57	Spares

5.2 Interval Time Increment Requirements

Timing intervals for the DARTS unit shall be either thumbwheel switch or pin programmable from the face of the unit. The following time intervals shall be provided:

0-5 seconds in 1-second increments or smaller
Primary T-1 Inbound
Alternate T-1 Inbound
Primary T-1 Outbound
Alternate T-1 Outbound

0-60 seconds in 1-second increments or smaller
Primary T-2 Inbound
Alternate T-2 Inbound
Primary T-2 Outbound
Alternate T-2 Outbound

0-30 seconds in 1-second increments or smaller
Primary T-3 Inbound
Alternate T-3 Inbound
Primary T-3 Outbound
Alternate T-3 Outbound

Primary T-4 Inbound
Alternate T-4 Inbound
Primary T-4 Outbound
Alternate T-4 Outbound

<u>0-30 seconds in 1-second increments or smaller</u> (Cont.)
Primary T-5 Inbound
Alternate T-5 Inbound
Primary T-5 Outbound
Alternate T-5 Outbound

<u>0-15 seconds in 1-second increments or smaller</u>
Primary T-6 Inbound
Alternate T-6 Inbound
Primary T-6 Outbound
Alternate T-6 Outbound

<u>0-5 seconds in 1-second increments or smaller</u>
Phase 3 Queue
Phase 4 Queue
Phase 7 Queue
Phase 8 Queue
Phase 1 Queue
Phase 5 Queue

<u>0-120 seconds in 2-second increments or smaller</u>
Phase 3 Time Waiting
Phase 4 Time Waiting
Phase 7 Time Waiting
Phase 8 Time Waiting
Phase 1 Time Waiting
Phase 5 Time Waiting
Phase 4 Ped. Time Waiting
Phase 8 Ped. Time Waiting

<u>0-15 seconds in 1-second increments or smaller</u>
Inbound Platoon Recognition (Phase 2)
Outbound Platoon Recognition (Phase 6)

5.3 <u>Indicator Lamps</u>

A separate indicator lamp shall be provided for each of the functions listed below to clearly indicate when one or more of the functions are in effect. It shall be easy to distinguish, when viewing the face of the unit at any distance up to four feet at any angle 45 degrees to the left or right in any lighting condition including direct sunlight, which indicator lamps are on and which indicator lamps are off.

Outbound	Inbound
1. T-1 Timing	1. T-1 Timing
2. T-2 Timing	2. T-2 Timing
3. T-3 Timing	3. T-3 Timing
4. T-4 Timing	4. T-4 Timing
5. T-5 Timing	5. T-5 Timing
6. T-6 Timing	6. T-6 Timing
7. Phase 5 Detector	7. Phase 1 Detector
8. Phase 5 Time Waiting Time Out	8. Phase 1 Time Waiting Time Out
9. Phase 5 Queue Detector	9. Phase 1 Queue Detector
10. Phase 5 Queue Time Out	10. Phase 1 Queue Time Out
11. Phase 7 Detector	11. Phase 3 Detector
12. Phase 7 Time Waiting Time Out	12. Phase 3 Time Waiting Time Out
13. Phase 7 Queue Detector	13. Phase 3 Queue Detector
14. Phase 7 Queue Time Out	14. Phase 3 Queue Time Out
15. Phase 8 Detector	15. Phase 4 Detector
16. Phase 8 Time Waiting Time Out	16. Phase 4 Time Waiting Time Out
17. Phase 8 Queue Detector	17. Phase 4 Queue Detector
18. Phase 8 Queue Time Out	18. Phase 4 Queue Time Out
19. Static Platoon	19. Static Platoon
20. Platoon Recognized	20. Platoon Recognized
21. Platoon Start	21. Platoon Start
22. Alternate Timing	22. Alternate Timing
23. Disable	23. Disable
24. Phase 6 Detector	24. Phase 2 Detector
25. Pedestrian Time Waiting Time Out	25. Pedestrian Time Waiting Time Out

An indicator lamp shall be provided for the 24 VDC power supply and the 120 VAC power source. The 120 VAC indicator need not be disabled.

5.4 A ground true input shall be provided to disable all incandescent indicator lamps in the DARTS unit.

5.5 The DARTS unit shall be designed to operate properly over a temperature range from -30°F to +165°F and over a voltage range of 95 volts to 135 VAC.

5.6 Timing within the DARTS unit shall be referenced to the sixty hertz line frequency as a time base.

5.7 All Force Off commands shall trail all other commands (omit hold, etc.) by approximately 200 ms.

5.8 The DARTS unit shall be modular in design and contained within a single metal enclosure. The DARTS unit shall be designed to be based within the cabinet that contains the traffic controller. The modules shall be readily accessible for maintenance and shall plug in the front of the case. No special tools shall be required to remove or replace the individual modules. Components requiring heat dissipation, such as the power supply transformer, filter capacitors, connectors, fuses, and lightning protection, may be mounted to the case assembly.

5.9 The card guides and motherboard assembly shall be contained within a painted metal enclosure that is easily removed and replaced. The enclosure design shall include vents. The maximum outside dimensions of the enclosure shall not exceed 12 inches in height, width, and depth. The Model and Serial Numbers shall be shown on the outside of the unit.

5.10 The module assemblies shall contain all of the logic and timing circuitry used within the DARTS unit. All of these electronic components shall be contained on printed circuit boards fabricated from FR-4 glass-epoxy, or equivalent having a minimum thickness of 1/16" with two ounces per square foot or more of copper track. Plated-through holes shall be plated with the equivalent of one ounce per square foot of copper.

The various printed circuit modules must be easily accessible and shall plug into their respective sockets in the case. All programming switches shall be contained on the front panel(s) and be accessible from the front of the unit, unless otherwise specified.

5.11 All of the electronic circuitry within the DARTS unit shall utilize CMOS integrated circuits with the exception of Input/Output drivers and buffers. Plug-in sockets (UL rated UV-9-V-D) shall be used for all Integrated Circuits. All circuits shall consist entirely of solid state electronic circuitry. Reed switches will not be permitted.

5.12 All components shall be amply derated with regard to heat dissipating capacity and rated voltage so that, with maximum ambient temperature and maximum applied voltage, the DARTS unit shall maintain its programmed functions.

5.13 The design life of all components, except for the batteries, under 24-hour per day ordinary operating conditions in their circuit operation, shall not be less than five years. The battery(ies) shall be capable of withstanding and operating within the temperature and humidity requirements of the controller assembly, and shall have a design life of at least four years under ordinary operating conditions. Any nickel-cadmium battery(ies) used shall be protected against cell polarity reversal at low voltages.

5.14 The DARTS unit shall contain a Slo-Blo fuse for the 120 volt, 60 Hz. AC supply. Also, a standard fuse shall be provided for the 24 volt DC external output from the unit. Values of fuses shall be of the proper value to protect the circuits involved.

6.0 INTERFACE PANEL

6.1 The Input and Output cables from the DARTS unit shall each terminate on terminal blocks mounted to a sturdy metal panel approximately twelve inches square and two inches deep that can be easily mounted on the side wall of the controller cabinet. These cables shall be a minimum of four feet long. All terminals shall be identified on the terminal end of the cables.

The cable(s) used to interconnect the interface panel with the various points in the controller cabinet shall be seven feet in length.

6.2 All cables shall be constructed of 22 AWG THW stranded wire (minimally). The ends of the cables that are to be attached to the controller terminals shall be appropriately labeled to facilitate installation in the field.

6.3 The following components shall be mounted on or plugged into the interface panel unless they are located in the DARTS unit.

1. Input and Output cables with quick disconnect connectors described elsewhere in this specification.

2. Sixteen lightning protection units. EDCO SRA-64-30 or Davis Engineering DE-64-30, or equivalent.

3. Octal base 120 VAC and fuse for the VOC flash input operation.

4. Switches for Inbound and Outbound Disable.

5. Phone jack.

6. External logic for Phase 2 and Phase 6 detector disable.

7.0 INTERCONNECT CABLE

7.1 The controllers and their DARTS units will be interconnected to others in a system using a multi-conductor 12 pair twisted, #24 AWG shielded control cable.

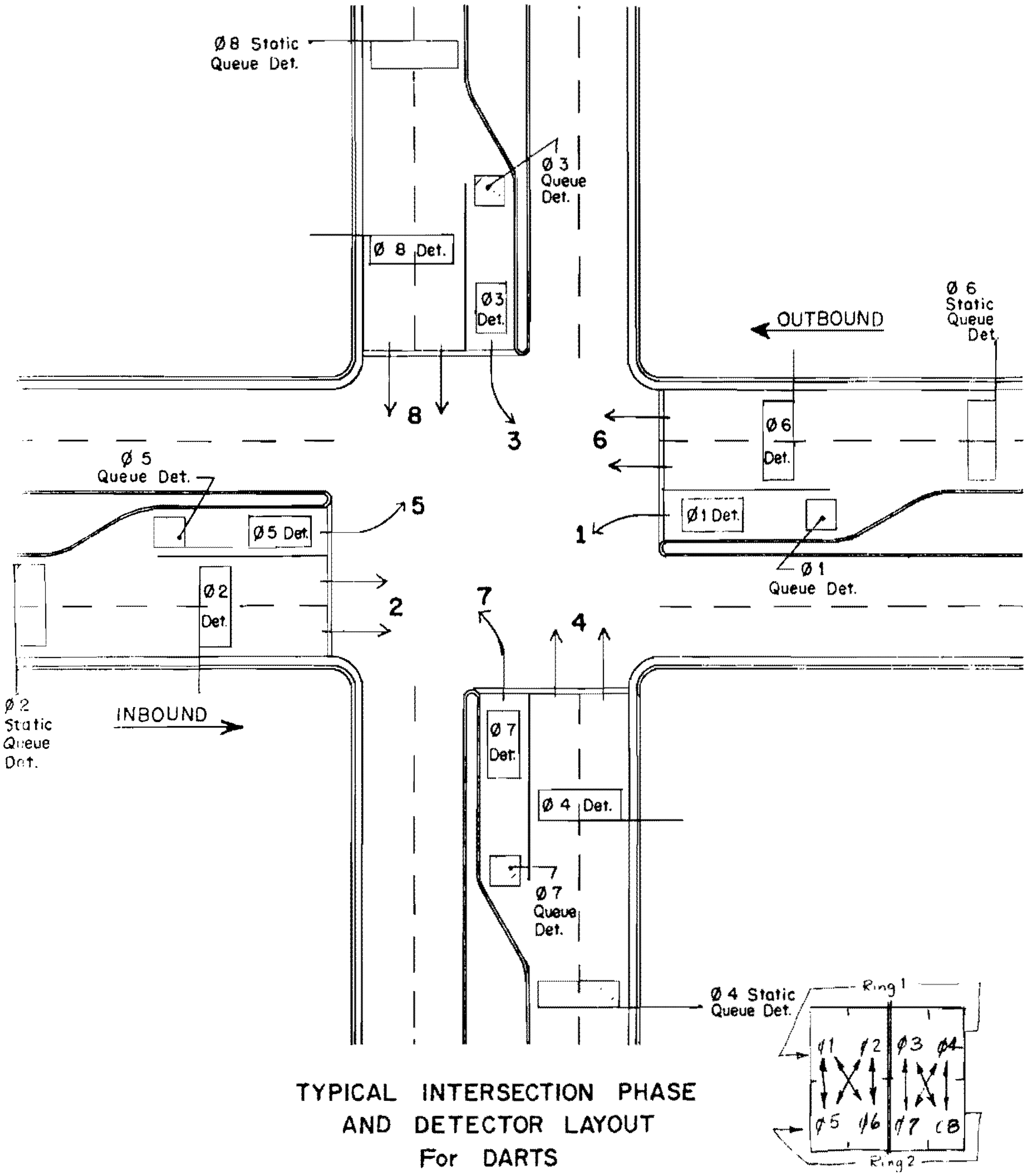
8.0 DOCUMENTATION AND SPARE EQUIPMENT

8.1 Each Dynamic Coordinating Unit shall be provided with the following information:

a) Two complete and accurate schematic diagrams for all circuitry in the Dynamic Coordination Unit.
b) Performance specifications (if any) on the unit.
c) Pictorial of components layout for each circuit board of individual component identification printed on each circuit board. Regardless of which of the above is provided, each integrated circuit on the boards will need to be clearly identified or labeled.
d) Service manual (if any) which describes operation, basic maintenance and troubleshooting information.

9.0 MEASUREMENT

Measurement shall be made of each complete Dynamic Arterial-Responsive Traffic System unit as specified in the Invitation to Bid.



TYPICAL INTERSECTION PHASE AND DETECTOR LAYOUT For DARTS

6-81-3050, D-18T

APPENDIX B

TABLE 1. BANDERA OUTBOUND TRAFFIC AT SENECA DARTS OFF

Time (p.m.) From	To	Volume (veh)	Delay (sec)	Avg. Delay (sec/veh)	Green (sec) (in 15-min)	Sec. Green Per Veh.	Avg. Cycle (in 15-min)	% Green (15 min)
3:30	3:45	274	222	0.81	670	2.45	58.0	74
3:45	4:00	190	1047	5.51	490	2.58	57.1	54
4:00	4:15	323	334	1.03	581	1.80	59.8	65
4:15	4:30	355	418	1.18	661	1.86	61.6	73
4:30	4:45	428	388	0.91	702	1.64	85.2	78
4:45	5:00	461	1954	4.24	642	1.39	86.2	71
5:00	5:15	503	2035	4.05	610	1.21	77.2	68
5:15	5:30	494	1418	2.87	627	1.27	87.4	70
5:30	5:45	356	575	1.62	552	1.55	73.0	61
5:45	6:00	432	987	2.28	671	1.55	68.1	75
6:00	6:15	364	917	2.52	503	1.38	60.9	56
6:15	6:30	270	374	1.39	582	2.16	48.3	65
	Total	4450	1069	--	7291	--	--	--
	Mean	371	889	2.37	608	1.74	68.6	68
	Std. Dev.	97	629	1.53	68	0.45	13.0	8

TABLE 2. BANDERA OUTBOUND TRAFFIC AT SENECA
DARTS OUTBOUND ON

Time(p.m.) From	To	Volume (veh)	Delay (sec)	Avg. Delay (sec/veh)	Green (sec) (in 15-min)	Sec. Green Per Veh.	Avg. Cycle (in 15-min)	% Green (15 min.)
3:30	3:45	238	128	0.54	723	3.04	78.5	80
3:45	4:00	274	426	1.55	537	1.96	63.5	60
4:00	4:15	268	582	2.17	607	2.26	64.1	67
4:15	4:30	336	984	2.93	622	1.85	70.8	69
4:30	4:45	378	689	1.82	642	1.70	80.2	71
4:45	5:00	358	1254	3.50	573	1.60	104.3	64
5:00	5:15	366	1001	2.73	622	1.70	80.1	69
5:15	5:30	514	1009	1.96	707	1.38	101.8	79
5:30	5:45	388	824	2.12	622	1.60	75.2	69
5:45	6:00	346	(714)	(2.06)	477	1.38	79.3	53
6:00	6:15	294	(521)	(1.77)	415	1.41	97.1	46
6:15	6:30	298	(535)	(1.80)	450	1.51	89.4	50
	Total	4058	8667	--	6997	--	--	--
	Mean	338	722	2.08	583	1.78	82.0	65
	Std. Dev.	73	310	0.74	97	0.47	13.6	11

TABLE 3. BANDERA OUTBOUND TRAFFIC AT SENECA
DARTS IN/OUTBOUND ON

Time(p.m.) From	To	Volume (veh)	Delay (sec)	Avg. Delay (sec/veh)	Green (sec) (in 15-min)	Sec. Green Per Veh.	Avg. Cycle (in 15-min)	% Green (15 min.)
3:15	3:30	240	270	1.12	600	2.50	60.8	67
3:30	3:45	254	277	1.09	660	2.60	60.3	73
3:45	4:00	292	367	1.26	577	1.98	60.8	64
4:00	4:15	312	459	1.47	625	2.00	83.2	69
4:15	4:30	332	668	2.01	618	1.86	57.4	69
4:30	4:45	350	607	1.73	566	1.62	77.1	63
4:45	5:00	376	1146	3.05	548	1.46	60.9	61
5:00	5:15	474	760	1.60	665	1.40	102.0	74
5:15	5:30	506	569	1.12	700	1.38	100.5	78
5:30	5:45	432	366	0.85	699	1.62	81.9	78
5:45	6:00	364	808	2.22	619	1.70	90.2	69
6:00	6:15	293	622	2.12	577	1.97	55.4	64
	Total	4225	6919	--	7454	--	--	--
	Mean	352	577	1.64	621	1.84	74.2	69
	Std. Dev.	84	254	0.63	51	0.40	17.1	6

TABLE 4. BANDERA OUTBOUND TRAFFIC AT GRISSOM
DARTS OFF

Time (p.m.) From	To	Volume (veh)	Delay (sec)	Avg. Delay (sec/veh)	Green (sec) (in 15-min)	Sec. Green Per Veh.	Avg. Cycle (in 15-min)	% Green (15 min)
3:30	3:45	190	135	0.71	681	3.58	47.7	76
3:45	4:00	225	265	1.18	665	2.96	52.7	74
4:00	4:15	251	296	1.18	683	2.72	58.9	76
4:15	4:30	254	174	0.68	722	2.84	50.0	80
4:30	4:45	290	366	1.26	684	2.36	71.2	76
4:45	5:00	308	241	0.78	680	2.21	60.7	76
5:00	5:15	378	1383	1.01	642	1.70	74.7	71
5:15	5:30	311	338	1.09	663	2.13	83.5	74
5:30	5:45	287	414	1.44	659	2.30	66.0	73
5:45	6:00	250	568	2.27	671	2.68	84.4	75
6:00	6:15	227	269	1.18	673	2.96	71.3	75
6:15	6:30	221	356	1.61	671	3.04	59.2	75
	Total	3192	3803	--	8094	--	--	--
	Mean	266	317	1.20	674	2.62	65.0	75
	Std. Dev.	51	115	.44	19	.51	12.3	2

TABLE 5. BANDERA OUTBOUND TRAFFIC AT GRISSOM
DARTS OUTBOUND ON

Time (p.m.) From	To	Volume (veh)	Delay (sec)	Avg. Delay (sec/veh)	Green (sec) (in 15-min)	Sec. Green Per Veh.	Avg. Cycle (in 15-min)	% Green (15 min)
3:30	3:45	170	258	1.52	720	4.24	61.6	80
3:45	4:00	219	146	0.67	639	2.92	63.5	71
4:00	4:15	209	183	0.88	680	3.25	63.6	76
4:15	4:30	260	505	1.94	640	2.46	51.9	71
4:30	4:45	306	295	0.96	693	2.26	64.1	77
4:45	5:00	275	501	1.82	668	2.43	80.1	74
5:00	5:15	328	693	2.11	687	2.09	79.6	76
5:15	5:30	330	358	1.08	701	2.12	72.2	78
5:30	5:45	298	286	0.96	726	2.44	72.6	81
5:45	6:00	260	398	1.53	726	2.79	69.3	81
6:00	6:15	253	216	0.85	707	2.79	66.9	79
6:15	6:30	242	130	0.54	714	2.95	61.2	79
	Total	3150	3969	--	8301	--	--	--
	Mean	262	331	1.24	692	2.73	67.2	77
	Std. Dev.	49	169	0.52	30	0.59	8.1	3

TABLE 6. BANDERA OUTBOUND TRAFFIC AT GRISSOM
DARTS IN/OUTBOUND ON

Time(p.m.) From	To	Volume (veh)	Delay (sec)	Avg. Delay (sec/veh)	Green (secs) (in 15-min)	Sec. Green Per Veh	Avg. Cycle (in 15-min)	% Green (15 min)
3:15	3:30	220	429	1.95	658	2.99	51.2	73
3:30	3:45	185	56	0.30	702	3.79	72.4	78
3:45	4:00	(214)*	(140)*	(0.65)*	616	2.88	72.8	68
4:00	4:15	(235)*	(195)*	(0.83)*	673	2.86	76.8	75
4:15	4:30	243	127	0.52	682	2.81	62.4	76
4:30	4:45	275	318	1.16	632	2.30	68.5	70
4:45	5:00	313	275	0.88	671	2.14	84.6	75
5:00	5:15	344	637	1.85	666	1.94	89.4	74
5:15	5:30	380	600	1.58	709	1.87	89.4	79
5:30	5:45	344	367	1.07	655	1.90	84.8	73
5:45	6:00	258	339	1.31	667	2.59	89.4	74
6:00	6:15	252	430	1.71	704	2.79	88.4	78
	Total	(3263)+	(3913)+	--	8035	--	--	--
	Mean	272	326	1.15	670	2.57	77.5	74
	Std. Dev.	60	181	0.54	28	0.57	12.4	3

* Average values computed to replace missing data points.

+ Totals include average values computed to replace missing data points.

TABLE 7. BANDERA SIDESTREET TRAFFIC AT GRISSOM
DARTS OUTBOUND ON

Time(p.m.) From	To	Volume (veh)	Delay (sec)	Avg. Delay (sec/veh)	Green (sec) (in 15-min)	Sec. Green Per Veh.	Avg. Cycle (in 15-min)	% Green (15 min)
3:30	3:45	78	910	11.67	65	0.83	61.6	7
3:45	4:00	60	971	16.18	84	1.40	63.5	9
4:00	4:15	88	794	9.02	94	1.07	63.6	10
4:15	4:30	68	850	12.50	105	1.54	51.9	12
4:30	4:45	71	1039	14.63	98	1.38	64.1	11
4:45	5:00	91	1636	17.98	122	1.34	80.1	14
5:00	5:15	113	1490	13.19	102	0.90	79.6	11
5:15	5:30	85	1077	12.67	77	0.91	72.2	9
5:30	5:45	91	1515	16.65	86	0.95	72.6	10
5:45	6:00	55	1337	24.31	78	1.42	69.3	9
6:00	6:15	96	805	8.39	84	0.88	66.9	9
6:15	6:30	81	972	12.00	78	0.96	61.2	9
	Total	977	13396	--	1073	--	--	--
	Mean	81	1116	14.10	89	1.13	67.2	10
	Std. Dev.	16	299	4.31	15	0.26	8.1	2

TABLE 8. BANDERA SIDESTREET TRAFFIC AT GRISSOM DARTS IN/OUTBOUND ON

Time(p.m.) From	To	Volume (veh)	Delay (sec)	Avg. Delay (sec/veh)	Green (sec) (in 15-min)	Sec. Green Per Veh.	Avg. Cycle (in 15-min)	% Green (15 min)
3:15	3:30	70	667	9.53	133	1.90	51.2	15
3:30	3:45	76	710	9.34	85	1.12	72.4	9
3:45	4:00	82	962	11.73	83	1.01	72.8	9
4:00	4:15	75	1090	14.53	76	1.01	76.8	8
4:15	4:30	74	978	13.22	86	1.16	62.4	10
4:30	4:45	84	1213	14.44	118	1.40	68.5	13
4:45	5:00	130	1405	10.81	103	0.79	84.6	11
5:00	5:15	182	2317	12.73	99	0.54	89.4	11
5:15	5:30	142	2146	15.11	92	0.65	89.4	10
5:30	5:45	151	1281	8.48	109	0.72	84.8	12
5:45	6:00	146	1835	12.57	127	0.87	89.4	14
6:00	6:15	106	1345	12.69	75	0.71	88.4	8
	Total	1318	15949	--	1186	--	--	--
	Mean	110	1329	12.10	99	0.99	77.5	11
	Std. Dev.	39	527	2.17	20	0.38	12.4	2

TABLE 9. BANDERA OUTBOUND LEFT TURN TRAFFIC AT GRISSOM DARTS OFF

Time(p.m.) From	To	Volume (veh)	Delay (sec)	Avg. Delay (sec/veh)	Green (sec) (in 15-min)	Sec. Green Per Veh.	Avg. Cycle (in 15-min)	% Green (15 min.)
3:30	3:45	73	--	--	204	2.79	47.7	23
3:45	4:00	64	--	--	199	3.11	52.7	22
4:00	4:15	76	--	--	206	2.71	58.9	23
4:15	4:30	72	--	--	226	3.14	50.0	25
4:30	4:45	98	--	--	242	2.47	71.2	27
4:45	5:00	104	--	--	279	2.68	60.7	31
5:00	5:15	111	--	--	265	2.39	74.7	29
5:15	5:30	126	--	--	271	2.15	83.5	30
5:30	5:45	122	--	--	293	2.40	66.0	33
5:45	6:00	137	--	--	275	2.01	84.4	31
6:00	6:15	98	--	--	287	2.93	71.3	32
6:15	6:30	96	--	--	213	2.22	59.2	24
	Total	1177	--	--	2960	--	--	--
	Mean	98	--	--	247	2.58	65.0	28
	Std. Dev.	23	--	--	36	0.37	12.3	4

TABLE 10. BANDERA OUTBOUND LEFT TURN TRAFFIC AT GRISSOM DARTS OUTBOUND ON

Time(p.m.) From	To	Volume (veh)	Delay (sec)	Avg. Delay (sec/veh)	Green (sec) (in 15-min)	Sec. Green Per Veh.	Avg. Cycle (in 15-min)	% Green (15 min.)
3:30	3:45	57	--	--	162	2.84	61.6	18
3:45	4:00	66	--	--	174	2.64	63.5	19
4:00	4:15	70	--	--	195	2.79	63.6	22
4:15	4:30	57	--	--	156	2.74	51.9	17
4:30	4:45	78	--	--	233	2.99	64.1	26
4:45	5:00	106	--	--	256	2.42	80.1	28
5:00	5:15	96	--	--	260	2.71	79.6	29
5:15	5:30	117	--	--	294	2.51	72.2	33
5:30	5:45	85	--	--	257	3.02	72.6	29
5:45	6:00	125	--	--	243	1.94	69.3	27
6:00	6:15	100	--	--	253	2.53	66.9	28
6:15	6:30	104	--	--	183	1.76	61.2	20
	Total	1061	--	--	2696	--	--	--
	Mean	88	--	--	225	2.57	67.2	25
	Std. Dev.	23	--	--	44	0.39	8.1	5

TABLE 11. BANDERA OUTBOUND LEFT TURN TRAFFIC AT GRISSOM DARTS IN/OUTBOUND ON

Time(p.m.) From	To	Volume (veh)	Delay (sec)	Avg. Delay (sec/veh)	Green (sec) (in 15-min)	Sec. Green Per Veh.	Avg. Cycle (in 15-min)	% Green (15 min.)
3:15	3:30	57	--	--	154	2.70	51.2	17
3:30	3:45	69	--	--	185	2.68	72.4	21
3:45	4:00	(76)*	--	--	162	(2.13)*	72.8	18
4:00	4:15	(81)*	--	--	195	(2.41)*	76.8	22
4:15	4:30	93	--	--	208	2.24	62.4	23
4:30	4:45	91	--	--	178	1.96	68.5	20
4:45	5:00	89	--	--	192	2.16	84.6	21
5:00	5:15	102	--	--	232	2.27	89.4	26
5:15	5:30	156	--	--	278	1.78	89.4	31
5:30	5:45	143	--	--	264	1.85	84.8	29
5:45	6:00	102	--	--	214	2.10	89.4	24
6:00	6:15	116	--	--	238	2.05	88.4	26
	Total	(1175)+	--	--	2500	--	--	--
	Mean	98	--	--	208	2.19	77.5	23
	Std. Dev.	29	--	--	39	0.29	12.4	4

* Average Values computed to replace missing data points.

+ Totals include average values computed to replace missing data points.

TABLE 12. BANDERA INBOUND TRAFFIC AT GRISSOM
DARTS OFF

Time(p.m.) From	To	Volume (veh)	Delay (sec)	Avg. Delay (sec/veh)	Green (sec) (in 15-min)	Sec. Green Per Veh.	Avg. Cycle (in 15-min)	% Green (15 min.)
3:30	3:45	220	1278	5.81	404	1.84	47.7	45
3:45	4:00	236	1545	6.55	413	1.75	52.7	46
4:00	4:15	202	1395	6.91	432	2.14	58.9	48
4:15	4:30	192	1209	6.30	403	2.10	50.0	45
4:30	4:45	198	2375	11.99	386	1.95	71.2	43
4:45	5:00	200	2627	13.14	340	1.70	60.7	38
5:00	5:15	--	--	--	334	--	74.7	37
5:15	5:30	--	--	--	352	--	83.5	39
5:30	5:45	--	--	--	330	--	66.0	37
5:45	6:00	--	--	--	360	--	84.4	40
6:00	6:15	--	--	--	346	--	71.3	38
6:15	6:30	--	--	--	391	--	59.2	43
	Total	1248	10429	--	4490	--	--	--
	Mean	208	1738	8.45	374	1.91	65.0	42
	Std. Dev.	17	607	3.23	35	0.18	12.3	4

TABLE 13. BANDERA INBOUND TRAFFIC AT GRISSOM
DARTS OUTBOUND ON

Time(p.m.) From	To	Volume (veh)	Delay (sec)	Avg. Delay (sec/veh)	Green (sec) (in 15-min)	Sec. Green Per Veh.	Avg. Cycle (in 15-min)	% Green (15 min.)
3:30	3:45	189	739	3.91	529	2.80	61.6	59
3:45	4:00	199	1061	5.33	401	2.02	63.5	45
4:00	4:15	196	1417	7.23	425	2.17	63.6	47
4:15	4:30	175	681	3.89	445	2.54	51.9	49
4:30	4:45	170	1333	7.84	424	2.49	64.1	47
4:45	5:00	246	1772	7.20	360	1.46	80.1	40
5:00	5:15	214	3935	18.39	392	1.83	79.6	44
5:15	5:30	194	1731	8.92	356	1.84	72.2	40
5:30	4:45	207	2525	12.20	414	2.00	72.6	46
5:45	6:00	216	1484	6.87	442	2.05	69.3	49
6:00	6:15	194	1814	9.35	398	2.05	66.9	44
6:15	6:30	160	1133	7.08	471	2.94	61.2	52
	Total	2360	19625	--	5057	--	--	--
	Mean	197	1635	8.18	421	2.18	67.2	47
	Std. Dev.	23	884	3.95	48	0.43	8.1	5

TABLE 14. BANDERA INBOUND TRAFFIC AT GRISSOM
DARTS IN/OUTBOUND ON

Time(p.m.) From	To	Volume (veh)	Delay (sec)	Avg. Delay (sec/veh)	Green (sec) (in 15-min)	Sec. Green Per Veh.	Avg. Cycle (in 15-min)	% Green (15 min.)
3:15	3:30	183	865	4.73	435	2.38	51.2	48
3:30	3:45	209	762	3.65	472	2.26	72.4	52
3:45	4:00	246	1357	5.52	433	1.76	72.8	48
4:00	4:15	231	1250	5.41	457	1.98	76.8	51
4:15	4:30	215	1146	5.33	423	1.97	62.4	47
4:30	4:45	198	2010	10.15	404	2.04	68.5	45
4:45	5:00	245	1843	7.52	476	1.94	84.6	53
5:00	5:15	243	2220	9.14	432	1.78	89.4	48
5:15	5:30	226	2181	9.65	401	1.77	89.4	45
5:30	5:45	269	5314	19.75	371	1.38	84.8	41
5:45	6:00	224	3359	15.00	421	1.88	89.4	47
6:00	6:15	244	1315	5.39	464	1.90	88.4	52
	Total	2733	23622	--	5189	--	--	--
	Mean	228	1968	8.44	432	1.92	77.5	48
	Std. Dev.	24	1276	4.77	31	0.25	12.4	4