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16. Abstract

TxDOT research project 0-4421 “A Simplified Approach for Selecting Optimal Traffic Responsive Control Parameters” developed procedures and guidelines for setting up and operating coordinated systems with the traffic responsive plan selection (TRPS) mode. This project implemented the TRPS mode at four locations in Texas using customized versions of the guidelines developed in research project 0-4421. Customization of the guidelines was necessary to account for the differences in certain site characteristics (e.g., available system detectors) between the implementation sites and the general site for which the original guidelines were developed. Locations were selected to represent a range of traffic conditions, arterial and detector configurations, and the two common controller types (Eagle and Naztec) used by TxDOT. The performance of the TRPS mode was evaluated by a comparison of average instantaneous and link speeds and delays determined before and after the implementation of the traffic responsive control. The before-after analyses indicated that the performance of the TRPS mode was in most cases better or at least as good as the existing systems. A step-by-step field manual to guide field technicians through the process of configuring their controllers to run a TRPS control was also developed and delivered to TxDOT to facilitate the implementation of the TRPS guidelines.

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IMPLEMENTATION OF TRAFFIC RESPONSIVE CONTROL ON TxDOT CLOSED-LOOP SYSTEMS

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DISCLAIMER

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INTRODUCTION

TxDOT research project 0-4421 "A Simplified Approach for Selecting Optimal Traffic Responsive Control Parameters" developed procedures and guidelines for operating coordinated systems with the traffic responsive plan selection (TRPS) mode *(1)*. Numerous parameters (i.e., detector weights, thresholds, timing plan look-up tables, TRPS timing plans, etc.) have to be set up correctly for the system to work as intended. As a result, traffic engineers have typically preferred to use the time of day mode of operation for its ease of setup, and TRPS mode has remained an underutilized resource due to the complexity of its configuration.

Research project 0-4421 developed guidelines for the selection of optimal TRPS system parameters and thresholds and presented them in tables and graphs for ease of implementation. The guidelines were developed for an arterial, consisting of three to six intersections, with two lanes in each direction, and with a system detector layout illustrated in Figure 1. It is assumed that the system detectors (detectors used for TRPS mode operation) are located far enough upstream of the stop lines that they are not affected by queues. The guidelines were verified using Hardware-in-the-Loop (HITL) simulations but were not implemented in the field. Based on HITL simulation results, an average savings of 53 percent in system delay and 19 percent in number of vehicle stops were predicted.

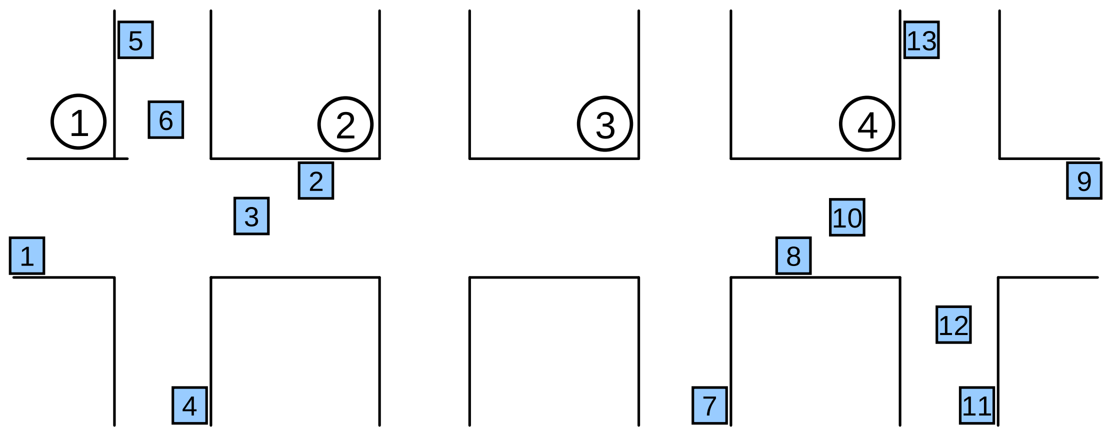


Figure 1. System Detector Configuration for the Guidelines Developed in Project 0-4421.

This project implemented the TRPS mode at four locations in Texas using customized versions of the guidelines developed in research project 0-4421. Customization of the guidelines was necessary to account for the differences in certain site characteristics (e.g., roadway geometry and availability of appropriate system detectors) between the implementation sites and the general site for which the original guidelines were developed.

OBJECTIVES

The main objectives of the implementation project were:

- Implement the TRPS guidelines developed in research project 0-4421 at selected arterials with three to six coordinated intersections operated as closed-loop systems.
- Evaluate the performance of the newly implemented TRPS mode relative to the existing systems at the selected study sites.
- Develop a Field Manual with step-by-step instructions for the setup of TRPS mode at locations with different site characteristics, vehicle detection modes, and controller types.

To achieve these project objectives the following tasks were completed:

- Select implementation sites.
- Identify any implementation issues and site-specific constraints.
- Customize guidelines.
- Conduct before studies.
- Implement TRPS mode.
- Conduct after studies.
- Evaluate system performance by comparing before and after study results.
- Develop a Field Manual.

SITE SELECTION

The research team visited several potential sites in Texas with the intent to identify five sites where the guidelines developed in research project 0-4421 can be implemented with or without modifications. The team contacted TxDOT staff in advance to arrange for the visits and to gather information about each particular site.

The implementation sites were selected based on the following criteria:

1. Availability of a closed-loop system and appropriate infrastructure, and
2. The willingness of the local district to allow the use of their site for this project and a commitment to provide incidental support in terms of staff time and any needed minor upgrades to the existing hardware and software for the implementation of TRPS mode of operation.

After careful consideration, the TTI team selected the following sites:

- Bandera Road, San Antonio (San Antonio District),
- S. Valley Mills Dr., Waco (Waco District),
- E. Milam St. (US 84), Mexia (Waco District),
- W. Commerce St. (US 67), Brownwood (Brownwood District), and
- Voss Ave. (US 77), Odem (Corpus Christi District).

For the case of any potential implementation-related issues at any of the five locations, a backup site was also identified: Bellmead Drive (US 84), Bellmead (Waco District).

The selected locations represent the most common controller types (Eagle and Naztec) and vehicle detection modes (video detection and inductive loops) used by TxDOT. As indicated in Figure 2, Eagle controllers were in use at all sites except in Brownwood.

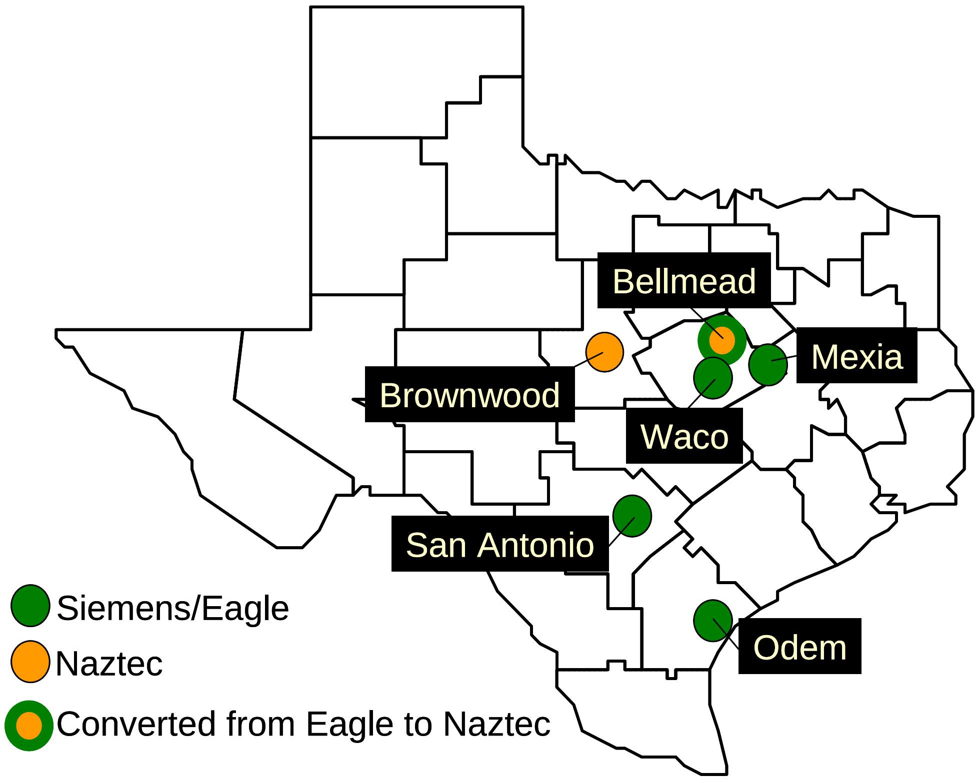


Figure 2. Implementation Sites.

IMPLEMENTATION ISSUES AND SITE-SPECIFIC CONSTRAINTS

This section discusses implementation issues and site-specific constraints (e.g., lack of appropriate system detectors) that prevented the use of the original guidelines and required customized implementation of the TRPS mode.

Four of the implementation sites, San Antonio, Brownwood, Waco, and Odem, used video detection, while Bellmead and Mexia used inductive loops for vehicle detection. Only one site with Naztec equipment located in the Brownwood District was suitable for applying the original guidelines developed in project 0-4421. At this site, the district staff had installed additional detectors, which communicated to the master controller (located in the signal shop) through wireless radios. However, after completing the before studies, the Brownwood site had to be dropped from the implementation list because of subsequent problems with the communication system between the master controller and system detectors. A private wireless network began interfering with TxDOT's wireless radio communications, and the issue could not be resolved during the period of this project.

Another site, where the original guidelines could have been implemented with minor modifications, was in Odem, Texas. The closed-loop system at this site used Eagle controllers. However, it was discovered later that system detectors were destroyed during a re-surfacing project at this site.

This left us with only four sites, all equipped with Eagle systems. One of these sites is located in the San Antonio District and the other three in the Waco District. It was highly desirable to represent both major vendors of controllers. With permission from the Waco District, the research team converted one site (located in Bellmead) from Eagle to Naztec. However, all four sites in this remaining set had one or more of the following problems:

1. The number of system detectors (existing or possible) was far fewer than the thirteen recommended in the original guidelines,
2. Existing (or possible) system detectors on the arterial were not (or could not be placed) far enough upstream to prevent queues at the stop bar from influencing volume and occupancy data (this issue and its implications are discussed below), and
3. Existing (or possible) system detectors on the cross streets were located (or could only be located) at the stop bar. Also, existing cross street detectors at three of the sites had lengths of more than three times the ideal length of 6 ft for system detectors.

Some potential problems associated with these detector configurations are explained and illustrated using Figure 3. In this figure, the eastbound approach has a 6×6 ft detector located 150 ft from the stop bar and a 6×20 ft stop bar detector on the northbound approach. The colored bars are used to illustrate queues of three different sizes at the two approaches.

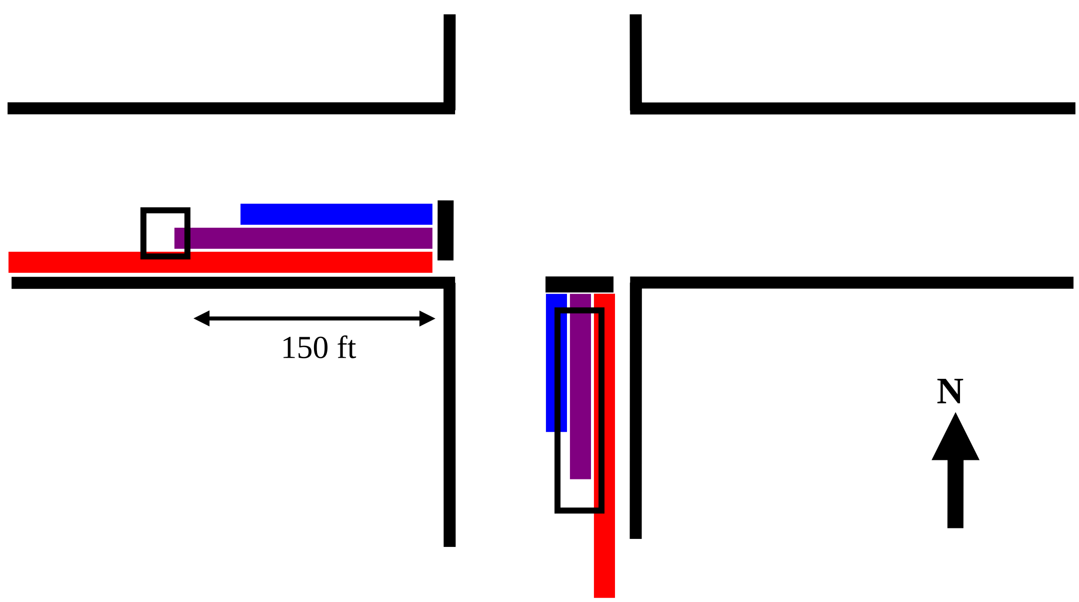


Figure 3. Potential Problems in Determining Traffic Demand Using the Detector Configuration Available at the Implementation Sites.

Assuming 25 ft to be the length of an average passenger car (vehicle length plus space between two stopped vehicles), a maximum of six cars can be queued at the eastbound stop bar without occupying the setback detector. If the demand is less than six vehicles per cycle (indicated by the blue bar), it is accurately determined from the detector count. Under such conditions, detector occupancy will increase as the queue size increases but will never be 100 percent. The increase in occupancy is due to the increasing passage time as each new vehicle approaches to join the end of the queue. However, once a queue reaches and occupies the detector (purple and red bars), the ability of a setback detector to differentiate between queues of various lengths sharply diminishes as all such queues result in similar occupancy values. Furthermore, the ability to get true demand is also lost since the detector can only count serviced volume, which is a function of phase capacity. It should be noted that the presence of a significant number of large trucks amplifies these results. Under such conditions, a desired approach might be to assume the worst-case scenario and significantly increase the cycle length in the next decision period. If the worst-case assumption is correct, this strategy will prevent grid-lock situations by flushing the system. However, if this assumption is incorrect, more accurate data collection will suggest a reduction in the cycle length at the next decision point. One consequence of such an approach is that the system may oscillate between a large and a small cycle length. The impacts of such oscillations can be reduced by selecting compatible cycle lengths needing minimal transition times. The researchers used this approach at the Mexia site.

As illustrated for the northbound approach, a stop bar detector does not provide good occupancy information to permit differentiation between different levels of demand. Furthermore, the ability to accurately count even the serviced volume degrades if the detector is longer than 25 ft. Other factors such as a single lane to serve all movements and presence of a busy driveway near the detection zone can further complicate the situation. To handle such movements served by actuated phases, researchers selected timing plans to accommodate the maximum anticipated demand, where unused capacity is automatically shifted to the coordinated phases. At one site (i.e., the Waco site) using video detection, no system detector definitions existed. Here the researchers defined short system detectors downstream of the stop bar and provided some slack time (excess capacity) for all phases.

The limited number of appropriate system detectors at the implementation sites makes it impossible to discriminate as many different traffic states as could be done using the system detector configuration assumed in the development of the original guidelines. Therefore, the system detectors available at the implementation sites would not work well with the original guidelines, and new customized guidelines are needed. The customized guidelines use fewer system detectors and discriminate fewer unique traffic states than the original guidelines. Consequently they are also expected to result in fewer timing plans than the original guidelines.

Since the scope of the project did not include major investment in detectorization, a decision had to be made to either abort the project or proceed with the implementation at these less-than-ideal sites. This latter option required significant modifications to the original guidelines to account for the given site-specific constraints. Although this latter option required more work than originally proposed, the research team decided to proceed with this option because of a realization that a majority of TxDOT facilities fit this category, and it is not feasible to make huge investments in installing and maintaining a large number of detectors required by the original guidelines. Furthermore, it is important to determine the kind of traffic-responsive operation that can be implemented at such sites.

CUSTOMIZATION OF GUIDELINES

As discussed in the previous section, the lack of appropriate system detectors required customization of the guidelines for each of the remaining four implementation sites. This meant that the type of work done in research project 0-4421 had to be repeated for each site. As in research project 0-4421, researchers conducted the following steps for each of the four sites:

1. *Select traffic states*

   In this step, the researchers collected existing traffic volume data in the field. Based on the field data, synthesized volume data were created to identify all traffic states that the site can encounter in the future.

2. *Develop optimal timing plans for each traffic state*

   The objective of this step was to select timing plans that provide good progression in both arterial directions. It was achieved by using a special version of PASSER V, specifically developed in project 0-4421. This version of PASSER V provides the following two features:

   - A batch mode for optimizing timing plans for all traffic states for a specified site.
   - A batch mode to evaluate a specified number of best timing plans for each state against all traffic states other than the one state used to generate these timing plans.

   The execution of this step in project 0-4421 did not place any constrains on the selection of timing plans. However, cycle lengths not synchronized with the data collection period can become sources of instability in a traffic responsive system, especially when some system detectors are not located at sufficient distance upstream to prevent influence of signal timings at a traffic signal. To illustrate this fact, consider a 95-second cycle length and a 10-minute (600-second) data collection period. Further assume that data collection begins at the main-street barrier. Note that 600 divided by 95 implies six (6) complete cycles plus an additional 30-second interval. Thus, the first 10-minute data will contain volumes and occupancies for the first six complete cycles and a portion of the seventh signal cycle. The following 10-minute data collection period will contain data for 65 seconds of the seventh signal cycle, data for the next five complete cycles, plus data corresponding to the first 65 seconds of the next cycle. The third sample will again have data for two partial cycles but of different lengths (35 and 90 second, respectively). Because of these partial cycles, data collected for consecutive 10-minute periods will not be consistent, potentially producing highly undesirable results in TRPS operation. Recognizing that this inconsistency could be significant for our sites with less than ideal system detectors, a decision was made to use a 10-minute data sample period for all implementation sites and constrain the selection of timing plans to only those cycle lengths that are divisors of this (600-second) data collection period. Thus, in this project, best timing plans with only 60-, 75-, 100-, 120-, and 150-second cycles were considered.

   It should also be noted that the best timing plans were developed to take advantage of actuated-coordinated operation, where unused green times from minor phases revert back to the coordinated phases. Timing plans developed to handle future high demand scenarios for cross streets (i.e., green split for phase 4 larger than that for phase 2) may appear to favor minor phases serving those movements. However, it should be kept in mind that the allocated splits will only be used by a minor phase if there is demand. In most cases, however, this time will revert back to the main street.

3. *Define system detectors and generate detector output*

   In this step, system detectors were defined using the existing set of detectors and, if needed, even using some of the available stop bar detectors. Then, a series of microscopic traffic simulation runs using TSIS/CORSIM™ were conducted to generate a sample of volume and occupancy data for (the locations and sizes of) detectors available at each site. These data would be used to obtain volume and occupancy thresholds in the next step. The simulations consisted of runs using timing plans generated in Step 3 against all traffic states identified for a site. For each site, this step required significantly less processing effort as compared to research project 0-4421. The reason was that now the detector locations were fixed whereas the objective of research project 0-4421 was to determine optimal number and locations of detectors. As in Step 2, a batch facility provided by TSIS was used to automate this process. Simulations were simultaneously run using half-dozen computers in the TransLink® lab at TTI.

4. *Determine detector weights and pattern selection parameter thresholds*

   In this step, discriminant analysis and multi-objective optimization was performed to determine detector weights and pattern selection (PS) parameter thresholds. A combination of manual and automated processing was used to complete this last step.

The following section shows how these steps were applied to customize the general guidelines for the Eagle system at the Mexia site. A similar approach was utilized for each of the other three implementation sites.

The Mexia network consists of three intersections in relatively close spacing as shown in Figure 4. The main street has protective-permissive left turn phases at each intersection. Left turns on the cross streets at intersections 1 and 2 are permissive-only. Intersection 3 was operated with split phasing on the side street. This ring operation was taken into consideration when designing the timing plans for the system.

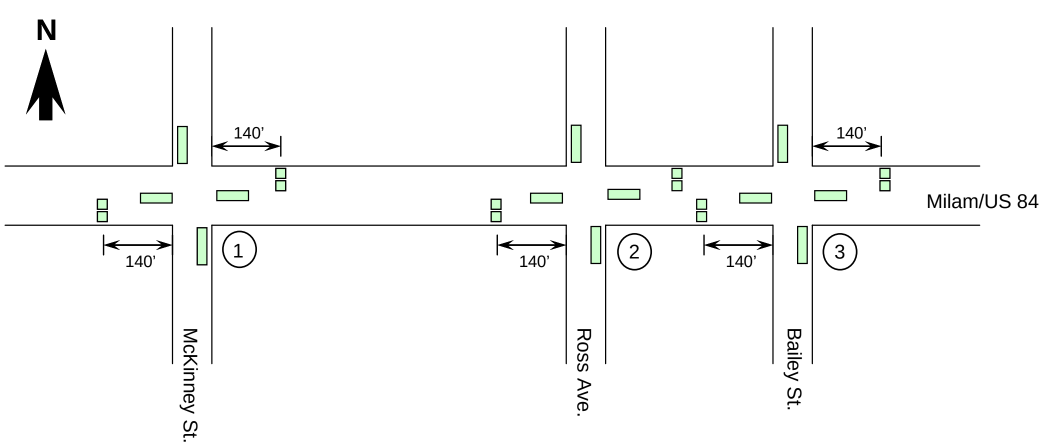


Figure 4. Mexia Site.

Selection of Traffic States

The general guidelines developed in project 0-4421 defined external and internal volume movements to be considered when selecting the traffic volume on the network as shown in Figure 5. The number and values of the levels for each movement was to be determined based on field data.

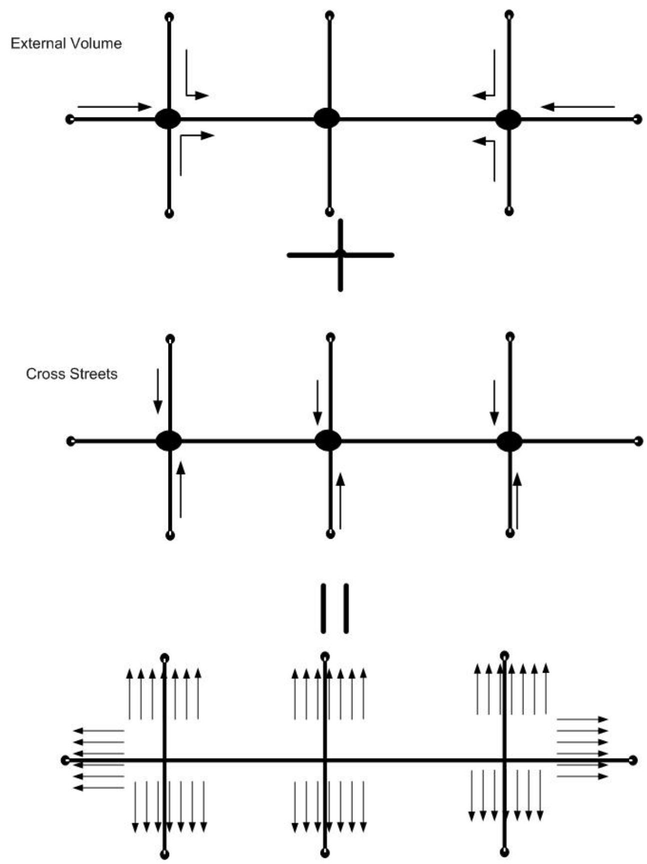


Figure 5. Generalized Arterial Volume Distribution.

Preliminary analysis and plots of field data were used to identify the levels for each movement used in this analysis. For example, the North Bound Right Turn external movement field data never exceeded 100 vehicles per hour. Therefore, only one level with a value of 100 vehicles per hour was considered for that movement in the analysis. The levels for each external movement are shown in Table 1. For each level of the internal local traffic, the internal turning movements were calculated based on an assumption that every node generates equal amount of trips and these trips get equally attracted by other nodes in the network. Levels and resulting interior turning volumes are shown in Table 2.

Table 1. Volume Levels for Arterial External Movements.

Level	External Movement					
	EB-Thru	SB-Left	NB-Right	WB-Thru	NB-Left	SB-Right
1	200	0	0	200	0	0
2	500	100	100	500	100	100
3	800	---	---	800	---	---

Table 2. Volume Levels for Internal Local Movements.

Cross Street Level	Volume	Intersection	Direction											
			East Bound			West Bound			North Bound			South Bound		
			L	T	R	L	T	R	L	T	R	L	T	R
1	150	1	25	100	25	111	86	111	21	21	107	107	21	21
		2	68	179	68	68	179	68	64	21	64	64	21	64
		3	111	86	111	25	100	25	107	21	21	21	21	107
2	300	1	50	200	50	221	171	221	43	43	214	214	43	43
		2	136	357	136	136	357	136	129	43	129	129	43	129
		3	196	171	196	50	200	50	214	43	43	43	43	214

Designing Timing Plans

PASSER V was used to develop timing plans for each of the states with 5 cycles each (60, 75, 100, 120, and 150 seconds). These cycle length values were considered because they are all divisors of a 10-minute sampling interval to be used with the TRPS. This is very important as it ensures that all data samples are collected by aggregating data from complete cycles, and not a fraction of a cycle. Next, PASSER V was run again to evaluate the performance of each of these timing plans with each of the original states, and a matrix of delay and number of stops was obtained for each of the combinations. A multi-objective optimization algorithm (*1*) was used to determine a maximum of 16 timing plans (a limitation imposed by traffic controllers) that would result in minimal delay, stops, and Degree of Detachment (DOD) among the traffic states. The DOD measures the degree by which a traffic state is different from adjacent states in terms of its timing plan. In this context, detachment occurs when the adjacent state (the state one level below or above the current state's level) is associated with a different timing plan. If timing plan assignments are scattered as small, mostly non-overlapping clusters throughout the state space, a high DOD value is obtained. Solutions with timing plan assignments forming large overlapping clusters in the state space have low DOD values.

The multi-objective optimization resulted in a selection of only four timing plans to handle all traffic states. The assignment of each traffic state to its timing plan is shown in Table 3. It can be observed that timing plans were assigned to adjacent traffic states to minimize the zigzag transitioning effects. The timing plans are shown in Table 4.

Table 3. Assignment of Traffic States to Timing Plans.

	State																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Plan	1	2	2	3	3	3	3	3	3	3	3	3	3	3	3	4	4	4

Table 4. Selected Timing Plans.

Timing Plan	Inter-section	Cycle	Phase							Leading Phases on Main-Street	Offset
			1	2	3	4	5	6	8		
1	1	75	15	31		29	15	31	29	1+5	33
	2	75	15	45		15	15	45	15	2 +5	22
	3	75	13	34	15	13	16	31		1+6	28
2	1	75	15	31		29	15	31	29	1+5	33
	2	75	15	45		15	15	45	15	2+5	22
	3	75	13	32	16	14	24	21		2+6	38
3	1	150	30	61		59	30	61	59	1+5	33
	2	150	30	90		30	30	90	30	1+5	97
	3	150	14	83	28	25	32	65		1+6	99
4	1	100	20	41		39	20	41	39	1+6	33
	2	100	20	60		20	20	60	20	1+6	49
	3	100	13	51	19	17	22	42		2+5	10

Define System Detectors and Generate Detector Output

The Mexia network has limited numbers of 6×6 ft detectors on the arterial (detectors 1-4 in Figure 6) that could be used as system detectors. There were no system detectors on the side street due to the fact that side street traffic was relatively low. However, in order to use TRPS, it was necessary to measure the level of side street traffic demand. One of the stop bar detectors was therefore configured and used as a system detector (detector 5 in Figure 6). It should be noted that stop bar detectors would provide higher occupancy values that should be taken into consideration. The Corridor Simulation (CORSIM) package (*2*) simulation was used with the specified detector length (20 ft) in order to account for that difference. The CORSIM network for the Mexia site is shown in Figure 7.

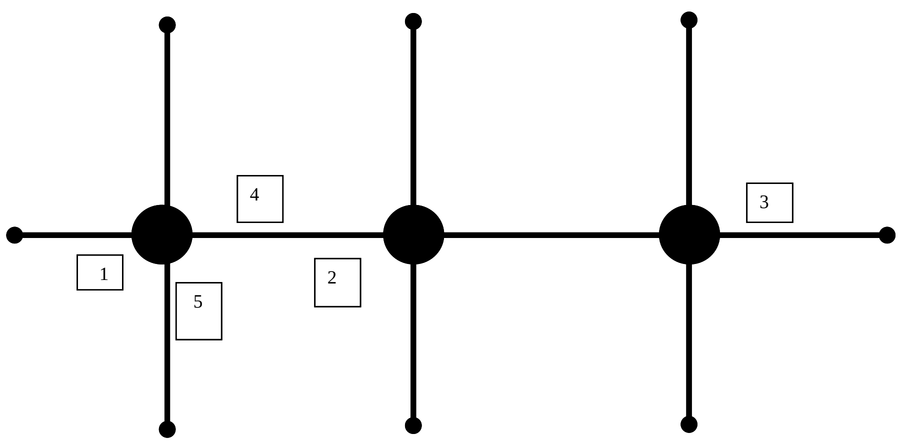


Figure 6. System Detector Locations.

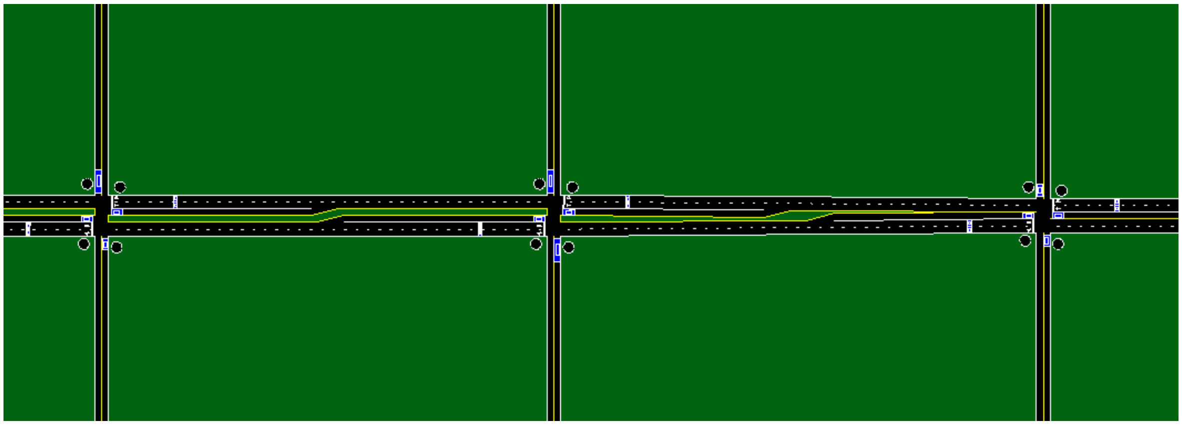


Figure 7. CORSIM Network for Mexia Site.

CORSIM files were processed and summarized. The counts and occupancies of the five system detectors are shown in Figure 8. The x-axis in these figures represents the ID of the CORSIM run result, where the y-axis represents the count/occupancy from the system detector. Each state was represented by four points on the x-axis to show the general trend in volume changes. It can be observed from these two figures that there is a systematic change in the system detector values as the overall volume changes as expected. Plotting of system detector values was found to be very valuable to (1) detect any configuration error, and (2) provide an insight into which system detector can be used to better represent a change in the overall traffic pattern in the system.

The next step was to assign each of the system detectors to the three PS parameters, with the objective of being able to separate each of the traffic states from the others.

Determine Detector Weights and PS Parameter Thresholds

System detectors 1 and 2 were assigned to the cycle PS parameter (calculated from the arterial channel in Eagle systems), where system detectors 3, 4, and 5 were assigned to the split PS parameter (calculated from the non-arterial channel in the Eagle system). The offset PS parameter was not used in this study, since it could have only resulted in changing the offset for the currently selected timing plan and not in selecting a different timing plan (*1*). The detector weights were adjusted so that the traffic states could be distinguished from each other. Figure 9 shows a plot of the traffic states on a cycle-split PS space. It should be noted that all states that were assigned to different timing plans could be separated from each other in the cycle-split PS space (some states were inseparable, but they were originally assigned to the same timing plan anyway). The thresholds were selected at points where the separation of states is clear. The weights and thresholds are listed in Table 5 and Table 6, respectively.

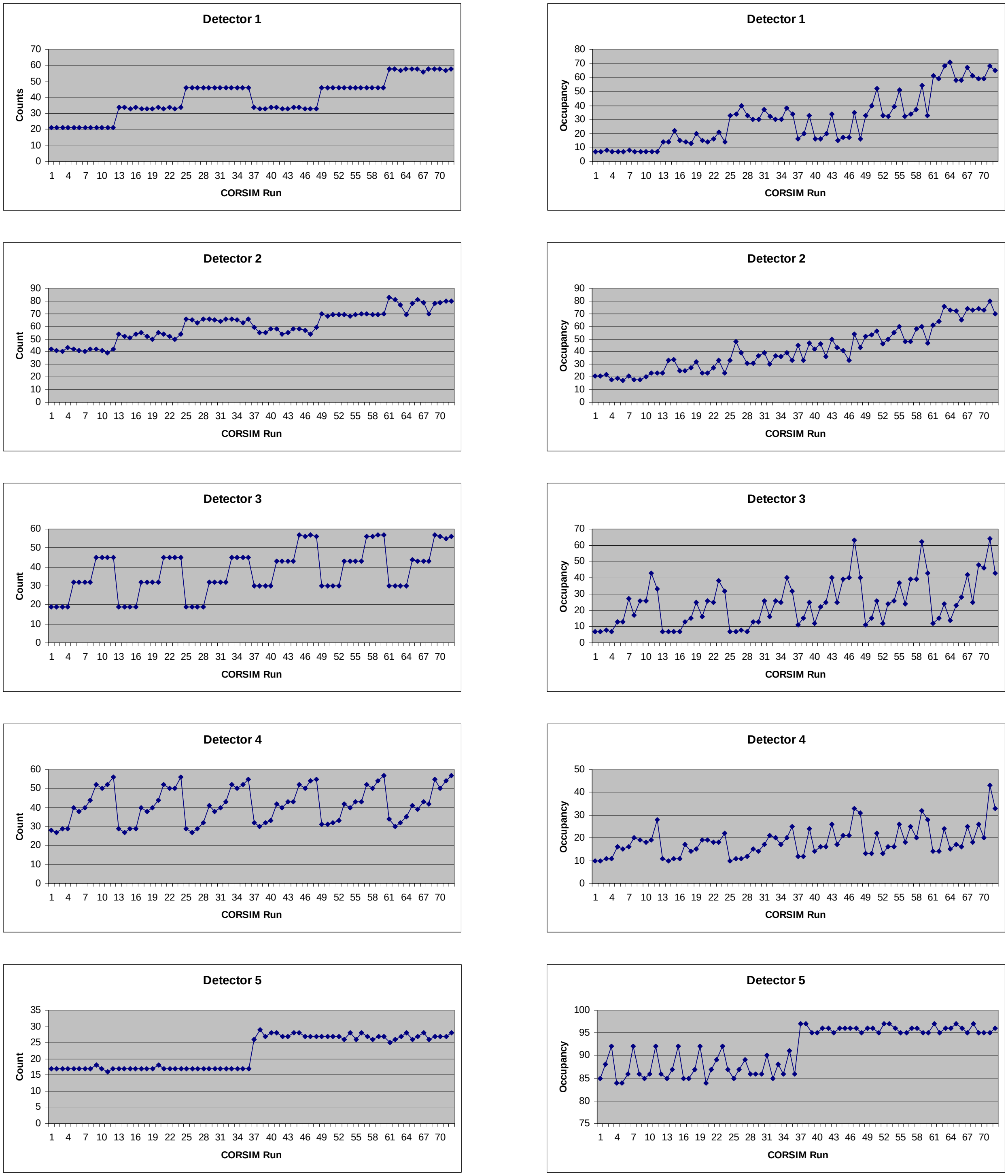


Figure 8. System Detector Counts and Occupancies.

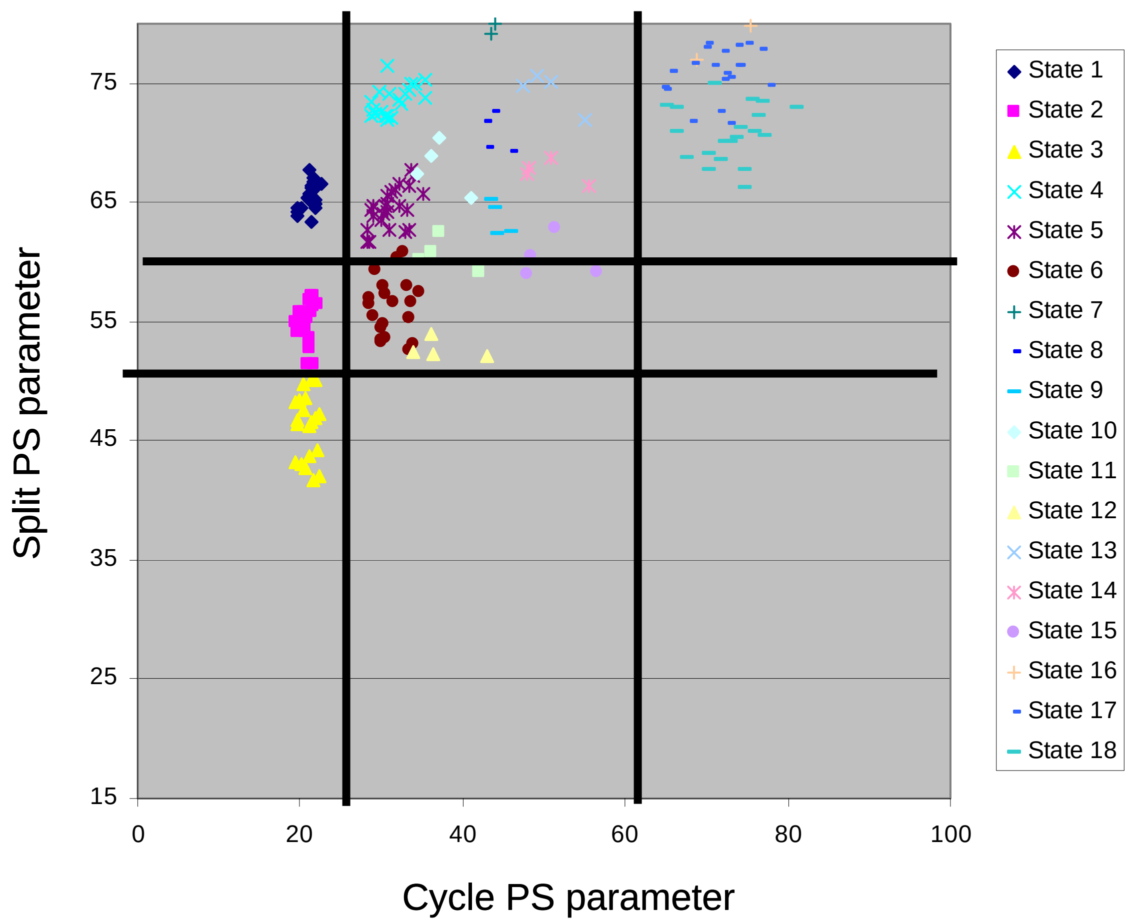


Figure 9. Threshold Selection and State Plots.

Table 5. Detector Weights.

System Detector Number	Channel	Detector Weight
1	Arterial	100
2	Arterial	80
3	Non-Arterial	100
4	Non-Arterial	80
5	Non-Arterial	10

Table 6. TRPS Thresholds.

Level	Cycle PS Parameter	Split PS Parameter
1	25	50
2	62	60

The approach illustrated above was used to customize the guidelines for all four implementation sites. Note that the customized guidelines developed for the implementation sites resulted in fewer timing plans than the general guidelines developed in project 0-4421. The primary reason for the smaller number of plans is associated with the limited number of appropriate system detectors at the implementation sites. A traffic responsive system using ideal system detectors can discriminate between traffic conditions with numerous combinations of volume scenarios and travel patterns. As such, the original guidelines contained more timing plans to target the wide range of different traffic conditions that could be identified. With less than ideal system detectors (i.e., fewer than the desired number, longer than 6 ft, and/or located within the influence of queues at the stop bar) present at the selected implementation sites, the data collected by the available system detectors did not have the discrimination power required to uniquely identify as many different demand and origin-destination patterns as desired. As a result, fewer timing plans were selected to cover only those traffic conditions that the detector data allowed to be differentiated.

The additional work of guideline customization has significantly added to the value of results from project 0-4421. If a site has (or can be easily configured to provide) an ideal system detector configuration (13 detectors located upstream of the influence of queues), the use of the original guidelines is recommended. However, if it is not feasible to provide an ideal detector configuration (the most likely scenario), the traffic responsive setup provided in this report for four additional sites may be adapted to provide an acceptable TRPS mode of operation.

"BEFORE" STUDIES

One of the objectives of the project was to evaluate the performance of the TRPS mode relative to the existing time of day (TOD) schedule at each study site. The evaluation was done based on the comparison of selected measures of effectiveness (MOEs) obtained before and after the implementation of the TRPS mode. The MOEs included arterial travel time, speed, and delay.

It should be noted here that the TRPS mode implemented in this project at each site was designed to provide good operation for existing conditions as well as for future conditions. Assessment of future conditions included normal growth but excluded pattern changes due to any future construction of major activity centers in the vicinity. Nonetheless, true evaluation of TRPS mode operation cannot be performed without long-term monitoring. The scope of this project did not include such a process. Thus, the only expectation was that the new operation performed at least as well as the existing one at each site.

The researchers visited all six sites, including the backup site in Bellmead, and conducted a series of travel time studies to assess the performance of the existing traffic signal systems (TOD) before the TRPS mode was implemented. The travel time studies included at least forty runs along the arterial at each study site using the floating car technique (*3*). The same driver drove the test vehicle at all study sites. Vehicle trajectories and speed data were collected using a Garmin® 18-5HZ GPS receiver and TS/PP-Draft 6.0© (*4*) software running on a laptop computer. To illustrate the data collection process, Figure 10 shows the speed profiles for two runs and the corresponding average instantaneous and average link speeds.

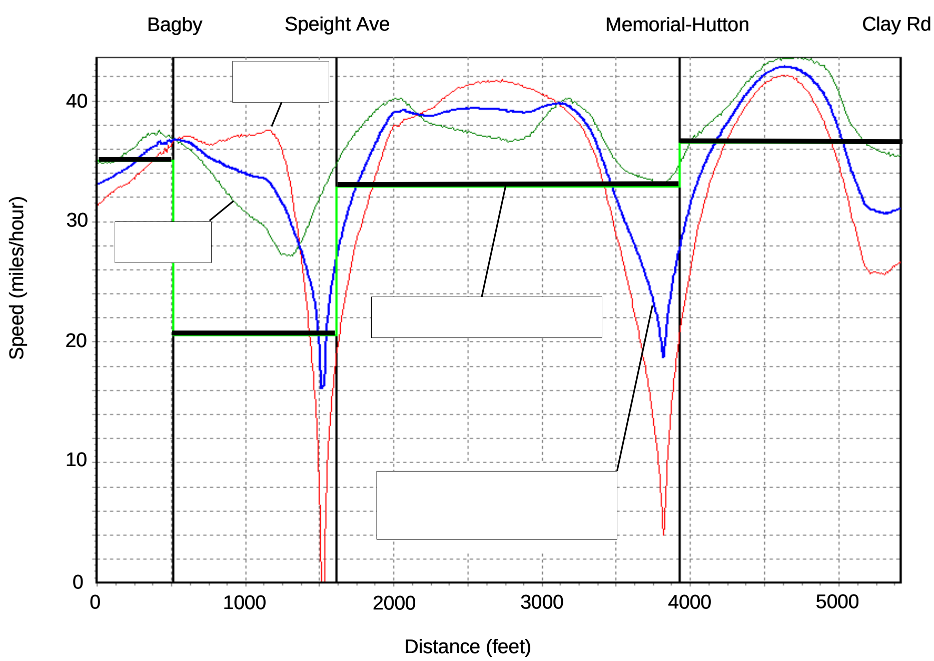


Figure 10. Speed Profiles Determined from Travel Time Studies.

In addition to the travel time studies, the research team also collected geometric information and volume data at each site. At four sites with video detection (San Antonio, Brownwood, Waco, and Odem) traffic on all key intersection approaches was recorded on four Digital Video Multiplexer Recorders (DVMRe) for 24 continuous hours. Then the video files were analyzed in the laboratory using Autoscope Solo Pro to extract volume data for each movement on each approach. This automated data extraction using directional count detectors is shown in Figure 11.

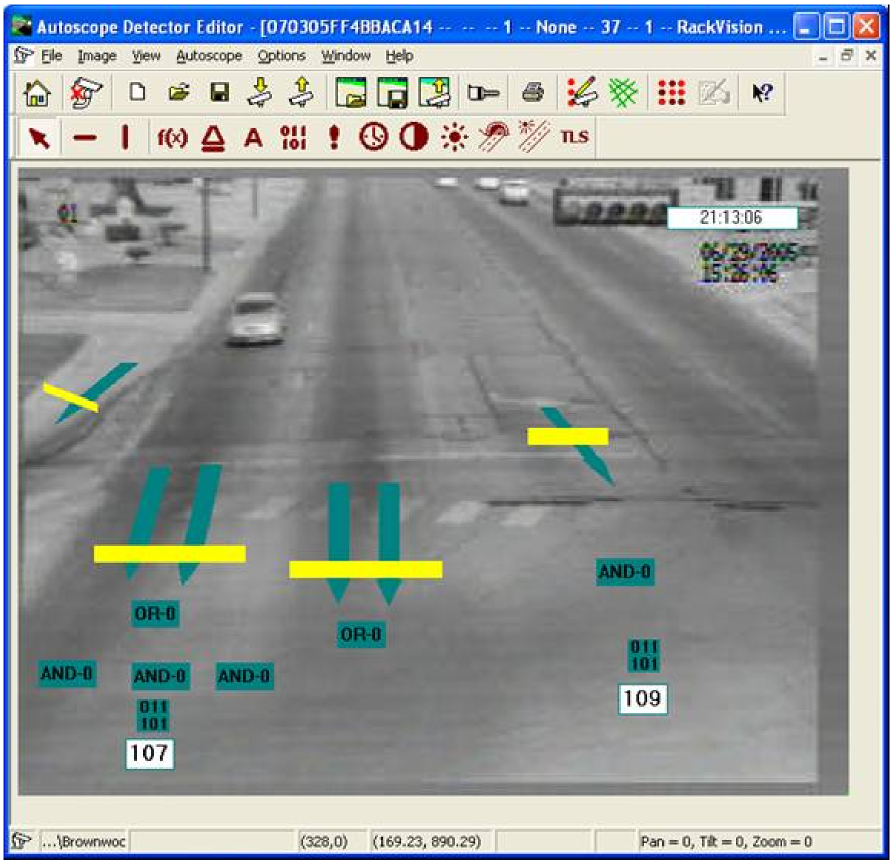


Figure 11. Volume Data Collection Using Autoscope.

The count data were aggregated in 10-minute intervals. To illustrate the process, 10-minute volume data collected over 24-hour period on all four approaches to the Huebner and Bandera Road intersection at the San Antonio site are shown in Figure 12. At two sites, where video detection was not available, traffic volumes were manually counted during the before studies. The Brownwood District also provided the research team with three weeks of system detector data for the purpose of calculating the frequency of different traffic states. The volume data collected during the before studies were essential to locate critical side streets (e.g., side streets with highest traffic demand) and to create different traffic state scenarios (i.e., different combinations of origin-destination patterns and demand levels) for customizing the guidelines.

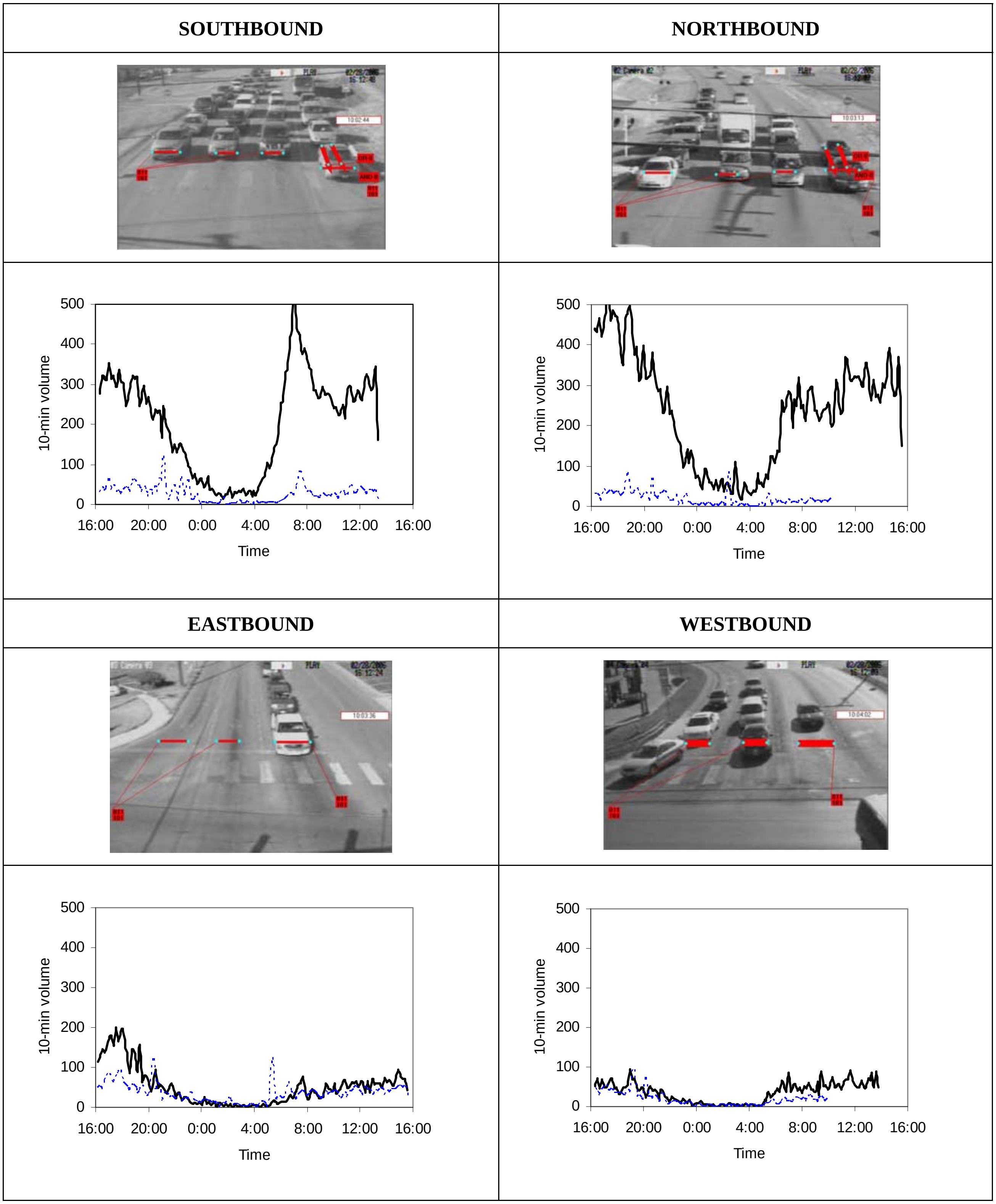


Figure 12. Ten-Minute Traffic Volumes at the Huebner and Bandera Intersection in San Antonio.

IMPLEMENT TRPS MODE

Obtain Closed-Loop Database from Each Site

The research team determined that the best communication mechanism for the purpose of this project is to maintain a closed-loop database for each of the selected sites and update the database with TxDOT-supplied information. This information includes a closed-loop software database created for each site (Streetwise© and ACTRA or MARC-NX©). The databases for all six sites were acquired by the time the before data were collected. At that time the research team was not aware of the implementation issues at two of the sites, in Brownwood and Odem, which were discussed in a previous section.

Eagle-to-Naztec Conversion at the Bellmead Site

As mentioned previously, removal of Brownwood from the list of implementation sites left the researchers with no Naztec-based closed-loop system. After consultation with TxDOT staff from the Waco District, the research team decided to convert one of the Waco District sites from an Eagle system to a Naztec system. The Waco District gave the researchers permission to perform this conversion at the implementation site in Bellmead. Although the extra work associated with this conversion caused some delay in the implementation schedule, it was necessary to ensure that both controller types are represented among the sites where the TRPS mode is implemented. The research team performed the following steps to convert the system:

1. Brought one master and four secondary Naztec controllers from Waco District signal shop to the TransLink® lab at TTI.
2. Programmed nine original timing plans in the Naztec controllers.
3. Replicated existing (Eagle) TOD schedule in secondary Naztec controllers.
4. Programmed base parameters in the Naztec master.
5. Installed the master in Waco signal shop and replaced the Eagle controllers in the field with the newly programmed Naztec controllers.
6. Conducted field observations to ensure that the Naztec controllers were working as intended.
7. Defined new databases for the master/secondary controllers in Waco District's Streetwise server and uploaded programmed data from field hardware.
8. Programmed newly customized TRPS parameters in the lab using StreetWise. These included three new patterns, which replaced the first three of the nine original patterns previously programmed (in step 2 above). In this step, the setup of TRPS operation in the master was also completed.
9. Copied revised StreetWise databases from the lab computer to the Waco District computer.
10. Downloaded the new databases from the district computer to field hardware.
11. Turned on and adjusted TRPS mode of operation.

The Waco District provided significant assistance in making the Eagle-to-Naztec conversion at the Bellmead site.

Define System Detectors and Determine Detector Weights and Thresholds

After eliminating two of the sites (Brownwood and Odem) the TRPS mode was implemented at four locations—three Eagle and one Naztec closed-loop system. The closed-loop databases as well as the geometric and volume data were reviewed in the TransLink® lab at TTI, and customized guidelines were developed for each of the four implementation sites using the steps described in the section titled CUSTOMIZATION OF GUIDELINES. The new guidelines account for the differences among the sites in geometry (e.g., number of lanes and intersections), available detection system (e.g., detector types, sizes, and locations), and the existence of some unique site characteristics (e.g., wide medians with frequent U-turns in San Antonio). Details on the system detectors, detector weights, and TRPS parameter thresholds for implementing TRPS mode of operation at each of the implementation sites are provided in the following four subsections.

E. Milam St (US 84), Mexia

The closed-loop system at the Mexia site consisted of three intersections as shown in Figure 13. The ring-barrier structure and defined alternate sequences are given in Table 7. The existing schedule and timing plans are summarized in Table 8 and Table 9. In the schedule table, Day 2 corresponds to Monday, and its schedule is equated to all weekdays. There is free operation between 7:00 PM and 7:00 AM on each weekday, and from 7:00 PM Friday to 7:00 AM Monday. Offsets are referenced to the main-street through-phase that starts first and are adjusted to progress eastbound traffic from the signal upstream of McKinney (not shown in Figure 13).

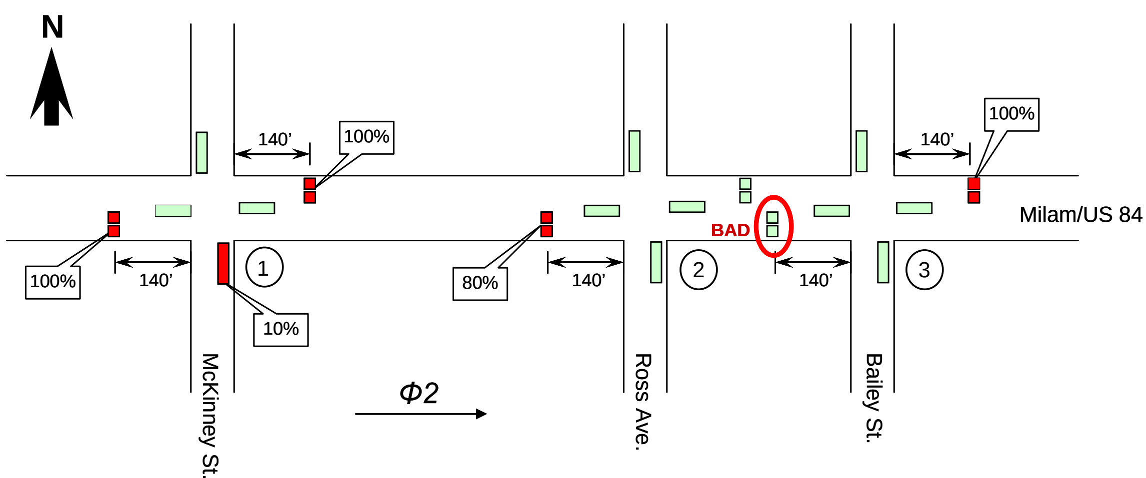


Figure 13. System Detectors and Detector Weights at the Mexia Site.

There were two major differences between the site shown in Figure 13 and the typical site illustrated in Figure 1. In Mexia, the number of available system detectors was smaller than required for the possible use of the original guidelines. The side streets had stop bar detectors only, and single-lane approaches with permissive-only phasing. Also, the advance detectors on the arterial were only 140 ft in advance of the stop lines, and the queues often extended beyond this distance. Because of these constraints, the general guidelines from project 0-4421 could not be applied, and new guidelines were developed as described in the section titled CUSTOMIZATION OF GUIDELINES. Table 10 and Table 11 contain the new schedule and recommended timing plans. This Eagle configuration uses four plans. The detector weights are given in Figure 13, and the entering and exiting thresholds for each timing plan are specified in Table 12. The initial value for exiting thresholds should typically be set 2 percent less than that of the corresponding entering thresholds until fine-tuned in the field. Table 13 lists the plan table look-up entries. Duplicate plans will need to be entered in each controller, which the user can do with the "Coordination Copy" feature in the Eagle controller.

Table 7. Ring-Barrier Structure and Alternate Phasing Sequences for the Mexia Site.

Intersection	Sequence 0 Phases 1+5 Lead	Sequence 1 Phase 2+5 Lead	Sequence 2 Phases 1+6 Lead	Sequence 3 Phases 2+6 Lead
1	1 2 4 5 6 8	2 1 4 5 6 8	1 2 4 6 5 8	2 1 4 6 5 8
2	1 2 4 5 6 8	2 1 4 5 6 8	1 2 4 6 5 8	2 1 4 6 5 8
3	1 2 3 4 5 6	2 1 3 4 5 6	1 2 3 4 6 5	2 1 3 4 6 5

Notes:
1. Phase 2: Eastbound through
2. Coordinated Phases: 2 and 6

Table 8. Existing Schedule for Mexia Site.

Program Day	Hour	Min	Pattern
2	7	0	1/1/1
2	7	30	2/1/1
2	8	30	1/1/1
2	15	30	2/1/1
2	17	0	1/1/1
2	19	0	Free(OFF=4)

Notes: Day 2 = 3,4,5,6

Table 9. Existing Timing Plans for the Mexia Site.

Timing Plan	Inter-section	Cycle	Phase							Leading Phases on Main-Street	Offset
			1	2	3	4	5	6	8		
1/1/1	1	75	12	36		27	12	36	27	1+6	33
	2	75	12	43		20	12	43	20	2+5	30
	3	75	12	27	18	18	12	27		1+5	30
2/1/1	1	75	12	36		27	12	36	27	1+6	33
	2	75	12	43		20	12	43	20	2+5	30
	3	75	12	27	18	18	12	27		1+5	0

Notes:
1. Signals 1 (McKinney) and 2 (Ross) have permissive-only phases 4 and 8
2. Signal 3 (Bailey) has split phasing (phases 3 and 4)
3. The offset at McKinney is set to progress eastbound traffic from SH 14 (signal upstream) through McKinney

Table 10. New Schedule for Mexia Site.

Local Schedule				Master Schedule				
1	7	0	1/1/1	2	7	0	1/1/1	1-TR>TBC
1	7	30	1/1/1	2	7	30	1/1/1	1-TR>TBC
1	8	30	1/1/1	2	8	30	1/1/1	1-TR>TBC
1	15	30	1/1/1	2	15	30	1/1/1	1-TR>TBC
1	17	0	1/1/1	2	17	0	1/1/1	1-TR>TBC
1	19	0	Free(OFF=4)	2	19	0	Free(OFF=4)	
Notes: Day 1 = Days 2, 3, 4, 5, 6, 7				Notes: Day 2 = Days 3, 4, 5, 6				

Table 11. Recommended New Timing Plans for the Mexia Site.

Timing Plan		Inter-Section	Cycle	Phase							Leading Phases on Main-Street	Offset
No	D/S/O			1	2	3	4	5	6	8		
1	1/2/1, 2/1/1 2/2/1, 2/3/1 2/4/1	1	75	15	31		29	15	31	29	1+5	33
		2	75	15	45		15	15	45	15	2 +5	22
		3	75	13	34	15	13	16	31		1+6	28
2	1/1/1, 1/3/1 1/4/1	1	75	15	31		29	15	31	29	1+5	33
		2	75	15	45		15	15	45	15	2+5	22
		3	75	13	32	16	14	24	21		2+6	38
3	3/1/1, 3/2/1 3/3/1, 3/4/1	1	150	30	61		59	30	61	59	1+5	33
		2	150	30	90		30	30	90	30	1+5	97
		3	150	14	83	28	25	32	65		1+6	99
4	4/1/1, 4/2/1 4/3/1, 4/4/1	1	100	20	41		39	20	41	39	1+6	33
		2	100	20	60		20	20	60	20	1+6	49
		3	100	13	51	19	17	22	42		2+5	10

Notes:
1. Only main-street phases were optimized
2. Offsets at McKinney are preserved to progress eastbound traffic from SH 14 (signal upstream) through McKinney.

Table 12. Eagle Controller TRPS Thresholds for Mexia Site.

Level	Cycle Select		Split Select	
	Enter	Leave	Enter	Leave
1	25	23	50	48
2	62	60	60	58
3	100	98	100	98

Table 13. Eagle Controller TRPS Plan Look-Up Table Entries for Mexia Site.

SPLIT	DIAL			
	1	2	3	4
1	1	1	3	4
2	2	1	3	4
3	2	1	3	4
4	2	1	3	4

In the Eagle TRPS implementation, the cycle select parameter does not become active until the parameter value reaches the third level (i.e., Levels 0 and 1 are reserved for free operation). Therefore, the entry levels provided in Table 12 should be programmed starting at the third level. In addition, the Eagle TRPS implementation of split select activates splits in the 2-1-3-4 order as the value of the split parameter increases. Therefore, columns 2 and 1 in Table 13 should be swapped to achieve the desired results. Table 14 provides this adjustment.

Table 14. Adjusted Eagle Controller TRPS Plan Look-Up Table Entries for Mexia Site.

SPLIT	DIAL			
	1	2	3	4
1	2	1	3	4
2	1	1	3	4
3	2	1	3	4
4	2	1	3	4

After downloading the new database for the TRPS mode, the researchers remained at the site and monitored traffic operations at each intersection to determine if any further adjustment or tweaking was needed. This practice was followed at all four implementation sites.

The following adjustments were made at the Mexia site:

1. On the northbound approach to the McKinney intersection, vehicles turning into and out of the gas station created long gaps in the vehicle stream that frequently resulted in premature gap-out on phase 8, as shown in Figure 14. The gap-reduction feature that was originally set for this movement did not work. Therefore, it was removed, and a 7-second passage time was set for the stop bar detector.

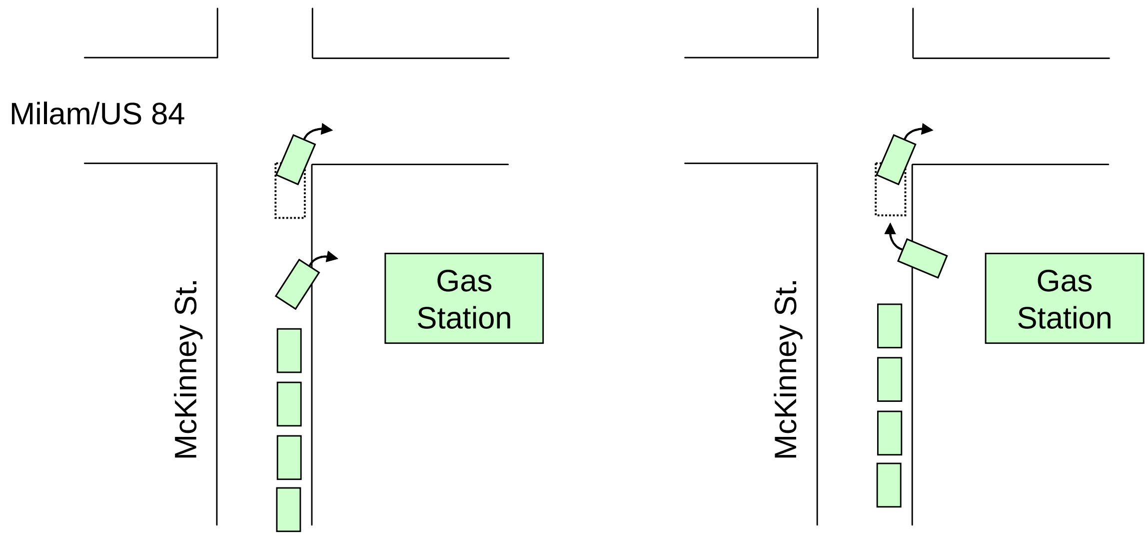


Figure 14. Increased Gaps due to Vehicles Turning in and out of the Gas Station.

2. Initially, the TRPS mode was set to operate at all times. However, several jumpy drivers were observed after 7 PM. They got used to the free operation at that time of the day. Therefore, researchers modified the schedule to switch from TRPS mode to free operation from 7 PM to 7 AM on weekdays, and from 7 PM Friday to 7 AM Monday.

Bellmead Dr (US 84), Bellmead

The closed-loop system at the Bellmead site consisted of four coordinated intersections. Figure 15 shows a sketch of the system. Similar to the Mexia site, the number of available system detectors was fewer than at the typical site shown in Figure 1, and the side streets had stop line detectors only. Also, the advance detectors on the arterial were only 110 feet in advance of the stop lines, and the queues often extended beyond this distance. Therefore, the general guidelines from project 0-4421 could not be applied, and new customized guidelines were developed as described in the CUSTOMIZATION OF GUIDELINES section.

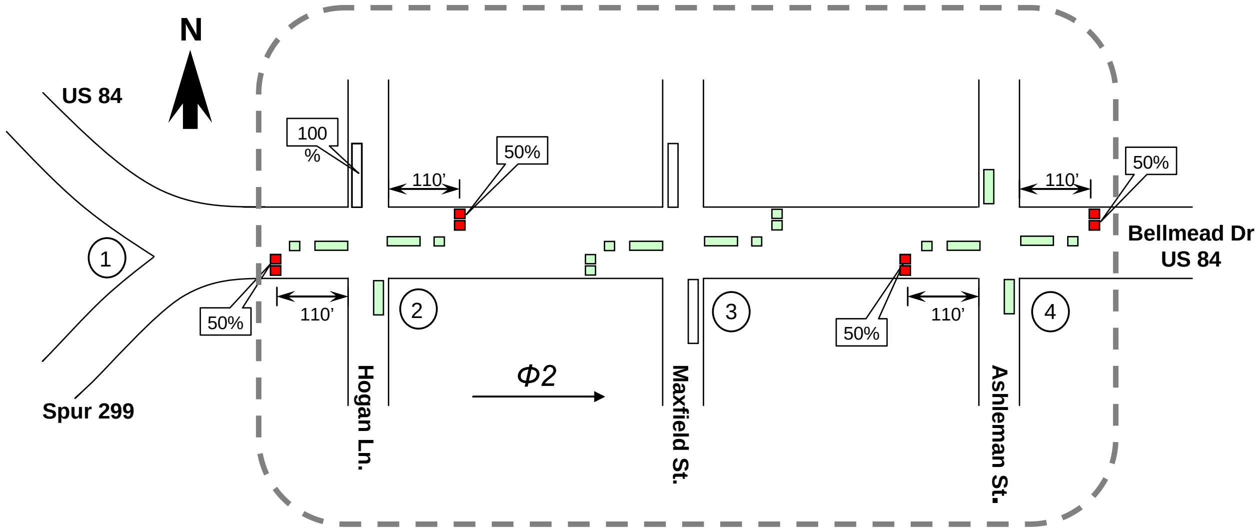


Figure 15. System Detectors and Detector Weights at the Bellmead Site.

The three signals (numbers 2, 3, and 4) used for traffic responsive operation at this site are identified by a rectangle with a dashed border. The fourth signal (number 1) in the system has three phases. This non-critical signal experienced balanced demand at the US 84 and Spur 299 approaches. Furthermore, phases 2 and 6 timed simultaneously to serve traffic to and from Spur 299 and phase 4 served eastbound through traffic into the signal system. Westbound traffic on US 84 does not stop at Spur 299. The ring-barrier structure and defined alternate sequences are given in Table 15. The existing schedule and timing plans are provided in Table 16 and Table 17. For each timing plan, equal (or approximately equal) green splits were allocated to signal phases 2+6 and 4.

The new schedule and recommended timing plans are shown in Table 18 and Table 19. The detector weights are given in Figure 15, and the entry and exit thresholds for each timing plan are specified in Table 20. The initial value for exiting thresholds should be set 2 percent less than that of the corresponding entering thresholds until fine-tuned in the field. Table 21 lists the plan table look-up entries.

Table 15. Bellmead Ring-Barrier Structure and Alternate Phasing Sequences.

Intersection	Sequence 1 Phases 1+5 Lead	Sequence 2 Phase 2+5 Lead	Sequence 3 Phases 1+6 Lead	Sequence 4 Phases 2+6 Lead
1	2 | 4 6 |			
2	1 | 2 | 4 5 | 6 | 8	2 | 1 | 4 5 | 6 | 8	1 | 2 | 4 6 | 5 | 8	2 | 1 | 4 6 | 5 | 8
3	1 | 2 | 4 5 | 6 | 8	2 | 1 | 4 5 | 6 | 8	1 | 2 | 4 6 | 5 | 8	2 | 1 | 4 6 | 5 | 8
4	1 | 2 | 4 5 | 6 | 8	2 | 1 | 4 5 | 6 | 8	1 | 2 | 4 6 | 5 | 8	2 | 1 | 4 6 | 5 | 8

Notes:

3. Phase 2: Eastbound through
4. Coordinated Phases: 2 and 6

Table 16. Existing Eagle Schedule for the Bellmead Site.

Program Day	Hour	Min	Pattern
1	6	0	1/1/1
1	18	0	Free(OFF=4)
2	6	0	1/1/1
2	18	0	Free(OFF=4)
7	6	0	1/1/1
7	18	0	Free(OFF=4)

Notes: Day 2 = 3,4,5,6

Table 17. Existing Eagle Timing Plans for the Bellmead Site.

Timing Plan	Inter-section	Cycle	Phase						Leading Phases on Main-Street	Offset
			1	2	4	5	6	8		
1/1/1	1	70		35	35		35			22
	2	70	11	40	19	11	40	19	1+5	0
	3	70	11	40	19	11	40	19	1+5	12
	4	70	11	40	19	11	40	19	1+5	25

Notes:

1. Signal at intersection 1 (Spur 299) has three phases only. It was tied to the system after selecting best timing plans for the other three signals (at Hogan, Maxfield, and Ashleman).
2. The other signals at intersections 2, 3, and 4 have permissive-only phasing on the cross street.
3. Offset at Spur 299 is set to progress platoons arriving from IH 35 interchange upstream of Spur 299 on the west side.

Table 18. New Naztec Schedule for the Bellmead Site.

Day Plan 01		
Event	Time	Action
1	6:00	1
2	18:00	10
Notes: Day Plan 01 runs every day of the week for the entire year		
Action Table		
Action	Master Coord. Mode	Pattern
1	TRI	1
10	TBC	254
Notes: Pattern 254 is Free Operation		

Table 19. Recommended Naztec Timing Plans for the Bellmead Site.

Timing Plan No.	Timing Plan D/S/O	Inter-section	Cycle	Phase 1	Phase 2	Phase 4	Phase 5	Phase 6	Phase 8	Leading Phases on Main-Street	Offset
1	1/1/1, 1/2/1	1	75		37	38		37			28
		2	75	15	30	30	11	34	30	2+6	28
		3	75	11	42	22	11	42	22	1+6	15
		4	75	11	34	30	15	30	30	2+5	59
2	2/1/1	1	120		60	60		60			28
		2	120	36	28	56	11	53	56	1+6	27
		3	120	23	53	44	19	57	44	1+6	30
		4	120	12	53	55	26	39	55	2+5	94
3	2/2/1	1	100		50	50		50			28
		2	100	24	32	44	11	45	44	1+6	13
		3	100	16	48	36	20	44	36	2+5	59
		4	100	11	42	47	28	25	47	1+5	65

Notes:
1. Only main-street phases were optimized.
2. Offsets are referenced to the main-street through phase that starts first and are further adjusted to progress eastbound traffic from the IH 35 interchange signal upstream of Spur 299 on the west side.

Table 20. Naztec Controller TRPS Thresholds for the Bellmead Site.

Level	Cycle Select Enter	Cycle Select Leave	Split Select Enter	Split Select Leave
1	40	38	50	48
2	100	98	100	98

Table 21. Naztec Controller TRPS Plan Look-Up Table Entries for the Bellmead Site.

SPLIT	DIAL 1	DIAL 2
1	1	2
2	1	3

The offsets were initially optimized to progress eastbound traffic from Spur 299. The offset at Spur 299 was further fine-tuned in the field to ensure that the eastbound platoons arriving at the US 84 approach from the upstream interchange (US 84 & IH 35) experienced no more than a few seconds of worst-case delay at Hogan Lane. This tweaking was done to ensure a smooth operation on the short link (about 450 ft) between Spur 299 and Hogan Lane.

Valley Mills Dr, Waco

The closed-loop system at the Waco site, shown in Figure 16, consisted of four intersections and used video detection only. At this site, no system detectors were defined. The existing video detection zones were too long to be used as system detectors, and they also had some occlusion problems. For our request, the Waco District increased the heights of the cameras and adjusted their angles to provide better fields of view for vehicle detection.

The researchers defined five system detectors located downstream of the stop bars, as indicated by red boxes in Figure 16. Each detector collected data across all lanes. Detector weights given as percentages are also shown in the figure. One of the system detectors originally defined at Clay Road could not be used because of a video camera malfunction. This non-working system detector, indicated by a red ellipse in Figure 16, was supposed to collect data on arterial traffic leaving the system in the westbound direction. The best alternative was to relocate this system detector to Dutton Rd. Although this new system detector location did not account for right-turn traffic from Dutton and left-turn traffic from Memorial, neither of these movements was critical.

Due to the differences in the number and locations of available system detectors between this site and the typical site shown in Figure 1, the general guidelines from project 0-4421 could not be used, and new customized guidelines were developed as described in the CUSTOMIZATION OF GUIDELINES section.

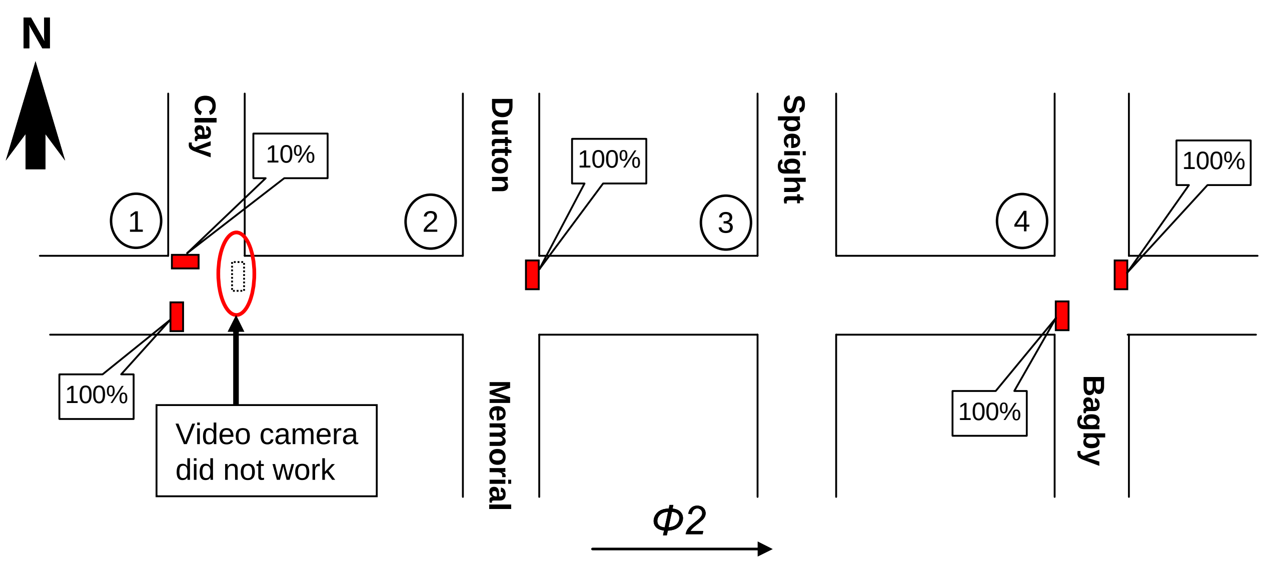


Figure 16. System Detectors and Detector Weights at the Waco Site.

The ring-barrier structure and defined alternate sequences for the Waco site are given in Table 22. The existing schedule and timing plans are provided in Table 23 and Table 24.

Table 22. Waco Ring-Barrier Structure and Alternate Phasing Sequences.

<table>
<tr><th>Intersection</th><th><u>Sequence 0</u>
Phases 1+5 Lead</th><th><u>Sequence 1</u>
Phase 2+5 Lead</th><th><u>Sequence 2</u>
Phases 1+6 Lead</th><th><u>Sequence 3</u>
Phases 2+6 Lead</th></tr>
<tr><td>1</td><td>2 | 4
5 | 6 |</td><td>2 | 4
6 | 5 |</td><td></td><td></td></tr>
<tr><td>2</td><td>1 | 2 | 3 | 4
5 | 6 |</td><td>2 | 1 | 3 | 4
5 | 6 |</td><td>1 | 2 | 3 | 4
6 | 5 |</td><td>2 | 1 | 3 | 4
6 | 5 |</td></tr>
<tr><td>3</td><td>1 | 2 | 3 | 4
5 | 6 |</td><td>2 | 1 | 3 | 4
5 | 6 |</td><td>1 | 2 | 3 | 4
6 | 5 |</td><td>2 | 1 | 3 | 4
6 | 5 |</td></tr>
<tr><td>4</td><td>1 | 2 | 3 | 4
5 | 6 |</td><td>2 | 1 | 3 | 4
5 | 6 |</td><td>1 | 2 | 3 | 4
6 | 5 |</td><td>2 | 1 | 3 | 4
6 | 5 |</td></tr>
<tr><td colspan="5">Notes:
1. Phase 2: Eastbound through
2. Coordinated Phases: 2 and 6</td></tr>
</table>

Table 23. Existing Schedule for the Waco Site.

Program Day	Hour	Min	Pattern
1	7	0	1/2/1
1	8	15	1/1/1
1	16	30	1/3/1
1	18	0	1/1/1
1	23	0	Free(OFF=4)
Notes: Day 1 = 2,3,4,5,6,7			

Table 24. Existing Timing Plans for the Waco Site.

Timing Plan	Inter-section	Cycle	Phase								Leading Phases on Main-Street	Offset
			1	2	3	4	5	6	7	8		
1/1/1	1	95		70		25	20	50			1+6	7
	2	95	16	37	21	21	16	37			2+5	55
	3	95	15	38	21	21	15	38			2+5	5
	4	95	15	35	24	21	13	37			1+6	10
1/2/1	1	87		65		22	12	53			2+5	15
	2	87	16	33	19	19	12	37			87	5
	3	87	16	33	19	19	19	30			1+6	49
	4	87	12	30	23	22	12	30			2+5	12
1/3/1	1	85		70		15	13	57			2+5	78
	2	85	12	41	17	15	16	37			1+6	81
	3	85	14	33	19	19	14	33			1+6	43
	4	85	11	40	19	15	11	40			2+5	76

The new schedule and recommended timing plans are given in Table 25 and Table 26. The Eagle configuration used at this site has three plans. The detector weights are given in Figure 16, and the entry and exit thresholds for each timing plan are specified in Table 27. The initial value for exiting thresholds should be set 2 percent lower than the corresponding entering thresholds, until fine-tuned in the field. The adjusted plan table look-up entries are listed in Table 28.

Table 25. New Schedule for the Waco Site.

Local Schedule				Master Schedule				
1	6	0	2/2/1	1	6	0	2/2/1	3-TR>=TBC
1	23	0	Free(OFF=4)	1	23	0	Free(OFF=4)	0-None
2	6	0	2/2/1	2	7	0	2/2/1	3-TR>=TBC
2	7	0	2/2/1	2	8	15	2/2/1	3-TR>=TBC
2	8	15	2/2/1	2	16	30	2/2/1	3-TR>=TBC
2	15	15	2/2/1	2	18	0	2/2/1	3-TR>=TBC
2	16	15	2/2/1	2	23	0	Free(OFF=4)	0-None
2	16	30	2/2/1					
2	18	0	2/2/1					
2	23	0	Free(OFF=4)					
Notes: Day 1 = Day 7, Day 2= Days 3, 4, 5, 6				Notes: Day 2 = Days 3, 4, 5, 6				

Table 26. Recommended Timing Plans for the Waco Site.

Timing Plan		Inter-section	Cycle	Phase								Leading Phases on Main-Street	Offset
No.	D/S/O			1	2	3	4	5	6	7	8		
1	1/1/1, 1/3/1 2/1/1, 2/3/1	1	120		80		40	15	65			2+5	0
		2	120	26	53	21	20	15	64			1+6	119
		3	120	19	64	17	20	17	66			2+6	64
		4	120	15	46	27	32	18	43			1+6	67
2	2/2/1, 3/1/1 3/2/1, 3/3/1	1	120		68		52	15	53			2+5	0
		2	120	27	37	29	27	15	49			1+6	118
		3	120	21	49	23	27	22	48			2+5	52
		4	120	15	38	30	37	24	29			1+6	67
3	1/2/1	1	120		68		52	15	53			2+5	0
		2	120	26	42	27	25	15	53			1+6	119
		3	120	19	51	23	27	22	48			1+5	64
		4	120	15	38	30	37	24	29			1+6	67

Table 27. Eagle Controller TRPS Thresholds for the Waco Site.

Level	Cycle Select		Split Select	
	Enter	Leave	Enter	Leave
1	43	41	53	51
2	55	53	60	58
3	100	98	100	98

Table 28. Adjusted Eagle Controller TRPS Plan Look-Up Table Entries for the Waco Site.

SPLIT	DIAL		
	1	2	3
1	1	1	2
2	3	2	2
3	1	1	2

Bandera Rd, San Antonio

The closed-loop system at the San Antonio site consisted of six intersections and used video detection. This is a six-lane facility with additional left-turn bays in each direction. In addition, it carries heavy traffic during peak periods. The traffic patterns are also more complex than all other implementation sites. The existing system at this location was already running under traffic responsive control based on occupancy thresholds. Furthermore, the existing operation used system detectors on the arterial at two locations. The research team configured a modified TRPS mode using three system detectors as shown in Figure 17. In the modified configuration, the system detector at Huebner Rd. was replaced by the system detector at Reindeer Trail. In addition, a system detector was added at Grissom.

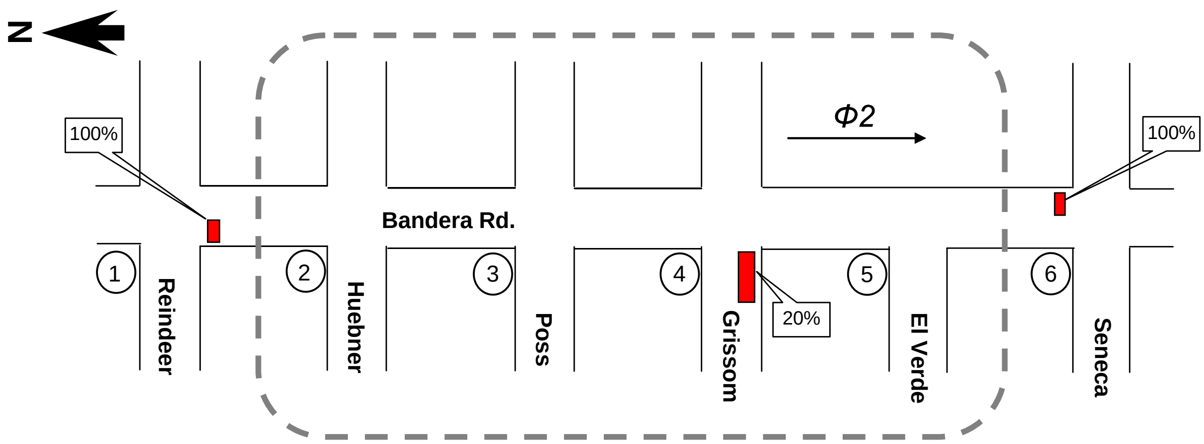


Figure 17. System Detectors and Detector Weights at the San Antonio Site.

The two system detectors on the arterial collected volume and occupancy data downstream of the signals, while the side street system detector on Grissom collected data on the dual left-turn lanes near the stop bar. At Grissom, the district defined a very long (>25 ft) detection zone across two lanes. This long stop bar detector used as a side street system detector did not have the ability to accurately count demand or even serviced volume. The occupancy values provided by the detector were also not good enough to permit reliable differentiation between different levels of demand. Due to the limited availability of appropriate system detectors, the general guidelines from project 0-4421 could not be used, and new guidelines were developed as described in the CUSTOMIZATION OF GUIDELINES section.

The ring-barrier structure and defined alternate sequences are given in Table 29. The existing schedule is shown in Table 30.

Table 29. San Antonio Ring-Barrier Structure and Alternate Phasing Sequences.

1	1 2 4 6 5 8	2 1 4 6 5 8	1 2 4 5 6 8	2 1 4 5 6 8
2	1 2 3 4 6 5 7 8	2 1 3 4 6 5 7 8	1 2 3 4 5 6 7 8	2 1 3 4 5 6 7 8
3	1 2 6 5 7 8	2 1 6 5 7 8	1 2 5 6 7 8	2 1 5 6 7 8
4	1 2 3 4 6 5	2 1 3 4 6 5	1 2 3 4 5 6	2 1 3 4 5 6
5	1 2 5 6 8	2 1 5 6 8	1 2 6 5 8	2 1 6 5 8
6	1 2 4 6 5 8	2 1 4 6 5 8	1 2 4 5 6 8	2 1 4 5 6 8

Notes:
1. Phase 2: Southbound through
2. Coordinated Phases: 2 and 6
3. Shaded phases not used but need to be defined because of non-standard cabinet wiring. It should be noted that the Eagle controller requires that the first ring be equal to the cycle length.

Table 30. Existing Schedule for the San Antonio Site.

Local Schedule				Master Schedule				
1	6	0	1/1/1	1	6	0	1/1/1	1-TR>TBC
1	10	45	1/1/1	1	9	45	1/1/1	1-TR>TBC
1	11	30	1/1/1	1	11	30	1/1/1	1-TR>TBC
1	12	30	1/1/1	1	12	30	1/1/1	1-TR>TBC
1	15	30	1/1/1	1	15	30	1/1/1	1-TR>TBC
1	17	0	1/1/1	1	17	0	1/1/1	1-TR>TBC
1	19	0	Free(OFF=4)	1	19	0	Free(OFF=4)	1-TR>TBC
2	4	30	Free(OFF=4)	2	4	30	Free(OFF=4)	1-TR>TBC
2	5	30	Free(OFF=4)	2	5	30	Free(OFF=4)	1-TR>TBC
2	6	45	2/1/2	2	6	45	2/1/2	1-TR>TBC
2	8	30	1/1/1	2	8	30	1/1/1	1-TR>TBC
2	8	45	1/1/1	2	8	45	1/1/1	1-TR>TBC
2	11	0	1/1/1	2	11	0	1/1/1	1-TR>TBC
2	13	0	1/1/1	2	13	0	1/1/1	1-TR>TBC
2	15	30	1/1/1	2	15	30	1/1/1	1-TR>TBC
2	15	45	2/3/3	2	15	45	2/3/3	1-TR>TBC
2	16	0	2/3/3	2	16	0	2/3/3	1-TR>TBC
2	19	30	Free(OFF=4)	2	19	30	Free(OFF=4)	1-TR>TBC
2	23	0	Free(OFF=4)	2	21	0	Free(OFF=4)	1-TR>TBC
Notes: Day 1 = Day 7, Day 2= Days 3, 4, 5, 6				Day 1 = Day 7, Day 2= Days 3, 4, 5, 6				

The plan selection parameter thresholds (cycle select and occupancy select) for the existing traffic responsive system are given in Table 31 and Table 32. The existing plan look-up table entries are given in Table 33. The dial-split combinations, which were actually used by the system, are indicated with bold border. The existing five timing plans are shown in Table 34.

Table 31. Eagle Controller Cycle Select Parameter Thresholds for Existing TRPS Operation at the San Antonio Site.

Level	Cycle Select	
	Enter	Leave
1	53	48
2	72	55
3	90	65

Table 32. Eagle Controller Occupancy Select Parameter Thresholds and Corresponding Forced Plans for Existing TRPS Operation at the San Antonio Site.

	OCC1		OCC2	
	Enter	Leave	Enter	Leave
Threshold	70	65	72	67
Forced Plan	2/3/3		2/1/2	

Table 33. Existing Eagle Controller TRPS Plan Look-Up Table Entries for the San Antonio Site.

SPLIT	DIAL			
	1	2	3	4
1	1	2	4	-
2	1	2	4	-
3	1	3	5	-
4	1	2	-	-

Table 34. Existing Timing Plans for the San Antonio Site.

Timing Plan	Inter-section	Cycle	Phase								Leading Phases on Main-Street	Offset
			1	2	3	4	5	6	7	8		
1	1	100	20	55		20	15	60		20	1+6	49
	2	100	20	35	15	30	20	35	25	20	1+6	0
	3	100	15	45		10	15	45	20	20	1+6	13
	4	100	27	32	30	11	10	35		10	1+6	20
	5	100	20	45		25	10	56		34	1+5	50
	6	100	25	45		30	25	45		30	1+6	53
2	1	115	17	64		34	13	60		16	1+6	0
	2	115	17	60	13	24	30	30	17	16	1+6	7
	3	115	17	64		10	17	64	17	17	1+6	30
	4	115	19	59	25	12	31	40		10	1+6	35
	5	115	18	63		25	10	63		34	1+5	100
	6	115	22	68		25	26	64		22	1+6	65
3	1	115	17	39		17	10	58		16	1+6	10
	2	115	26	28	18	24	20	52	25	18	1+6	110
	3	115	13	60		10	13	68	17	17	1+6	81
	4	115	35	41	17	22	11	65		10	1+6	80
	5	115	16	65		25	10	65		34	1+5	107
	6	115	22	67		26	22	67		22	1+6	53
4	1	130	19	72		38	15	68		18	1+6	0
	2	130	19	68	15	27	34	34	19	18	1+6	7
	3	130	19	72		11	19	72	19	19	1+6	30
	4	130	21	67	28	14	35	45		10	1+6	35
	5	130	20	71		28	11	71		38	1+5	100
	6	130	25	77		28	29	72		25	1+6	65
5	1	130	19	72		38	15	68		18	1+6	17
	2	130	29	32	20	27	23	59	28	20	1+6	110
	3	130	15	68		11	15	77	19	19	1+6	81
	4	130	40	46	19	25	12	73		10	1+6	80
	5	130	18	73		28	11	73		38	1+5	77
	6	130	25	75		30	25	75		25	1+6	53

The new schedule is shown in Table 35. The detector weights are given in Figure 17, and the entry and exit thresholds for each timing plan are specified in Table 36. The initial value for exiting thresholds should be set 2 percent less than that of the corresponding entering thresholds, until fine-tuned in the field. The new adjusted plan table look-up entries are listed in Table 37. The recommended new timing plans are given in Table 38.

Table 35. New Schedule for the San Antonio Site.

Local Schedule				Master Schedule				
1	6	0	1/3/1	1	6	0	1/3/1	1-TR>TBC
1	10	45	1/3/1	1	9	45	1/3/1	1-TR>TBC
1	11	30	1/3/1	1	11	30	1/3/1	1-TR>TBC
1	12	30	1/3/1	1	12	30	1/3/1	1-TR>TBC
1	15	30	1/3/1	1	15	30	1/3/1	1-TR>TBC
1	17	0	1/3/1	1	17	0	1/3/1	1-TR>TBC
1	19	0	Free(OFF=4)	1	19	0	Free(OFF=4)	1-TR>TBC
2	4	30	Free(OFF=4)	2	4	30	Free(OFF=4)	1-TR>TBC
2	5	30	Free(OFF=4)	2	5	30	Free(OFF=4)	1-TR>TBC
2	6	45	1/3/1	2	6	45	1/3/1	1-TR>TBC
2	8	30	1/3/1	2	8	30	1/3/1	1-TR>TBC
2	8	45	1/3/1	2	8	45	1/3/1	1-TR>TBC
2	11	0	1/1/1	2	11	0	1/1/1	1-TR>TBC
2	13	0	1/1/1	2	13	0	1/1/1	1-TR>TBC
2	15	30	1/1/1	2	15	30	1/1/1	1-TR>TBC
2	15	45	3/1/1	2	15	45	3/1/1	1-TR>TBC
2	16	0	3/1/1	2	16	0	3/1/1	1-TR>TBC
2	19	30	Free(OFF=4)	2	19	30	Free(OFF=4)	1-TR>TBC
2	23	0	Free(OFF=4)	2	21	0	Free(OFF=4)	1-TR>TBC
Notes: Day 1 = Day 7, Day 2= Days 3, 4, 5, 6				Day 1 = Day 7, Day 2= Days 3, 4, 5, 6				

Table 36. Eagle Controller TRPS Thresholds for the San Antonio Site.

Level	Cycle Select		Split Select	
	Enter	Leave	Enter	Leave
1	42	39	53	51
2	54	52	61	59
3	61	59	70	68
4	100	98	100	98

Table 37. Adjusted Eagle Controller TRPS Plan Look-Up Table Entries for the San Antonio Site.

SPLIT	DIAL			
	1	2	3	4
1	3	3	4	4
2	4	4	5	5
3	1	1	2	2
4	1	1	1	1

Table 38. Recommended Timing Plans for the San Antonio Site.

Timing Plan No.	Timing Plan D/S/O	Inter-section	Cycle	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5	Phase 6	Phase 7	Phase 8	Leading Phases on Main-Street	Offset
1	1/3/1, 1/4/1 2/3/1, 2/4/1 3/4/1, 4/4/1	1	100	15	66		19	15	66		19	1+6	0
		2	100	26	30	20	24	25	31	24	20	1+6	11
		3	100	10	68	12	10	15	63	11	11	2+6	62
		4	100	18	41	30	11	25	34			1+5	66
		5	100	15	65	10	10	14	66		20	2+6	53
		6	100	19	50		31	20	49		31	2+5	7
2	3/3/1, 4/3/1	1	100	19	58		23	15	62		23	1+5	0
		2	100	16	33	20	31	25	24	26	25	1+6	10
		3	100	11	64	13	12	15	60	12	13	2+6	51
		4	100	18	41	30	11	22	37			1+5	61
		5	100	15	65	10	10	14	66		20	2+6	45
		6	100	13	50		37	24	39		37	2+5	96
3	1/1/1, 2/1/1	1	100	25	43		32	15	53		32	2+5	0
		2	100	25	21	11	43	15	31	41	13	1+6	97
		3	100	14	60	14	12	15	59	12	14	2+6	47
		4	100	19	31	39	11	14	36			2+6	57
		5	100	15	65	10	10	14	70		16	2+5	29
		6	100	14	46		40	16	44		40	2+5	92
4	1/2/1, 2/2/1 3/1/1, 4/1/1	1	100	25	43		32	15	53		32	1+5	0
		2	100	40	21	11	28	16	45	26	13	1+6	92
		3	100	16	59	13	12	15	60	12	13	1+6	41
		4	100	32	26	28	14	14	44			1+5	49
		5	100	15	65	10	10	14	66		20	1+6	39
		6	100	25	33		42	13	45		42	2+5	0
5	3/2/1, 4/2/1	1	120	30	52		38	15	67		38	1+6	0
		2	120	49	25	11	35	19	55	32	14	2+5	79
		3	120	18	72	16	14	17	73	14	16	2+5	61
		4	120	39	31	34	16	17	53			1+6	69
		5	120	15	85	10	10	17	83		20	2+5	0
		6	120	30	40		50	15	55		50	2+6	28

Update Databases for TRPS Mode

The researchers reprogrammed the ACTRA, Marc-NX, and/or Streetwise databases for all implementation sites to configure them according to the customized TRPS guidelines. All programming activities were performed in the TransLink® lab at TTI.

Verify Expected Performance of the Updated Databases

Hardware in the Loop Simulations

Hardware-in-the-Loop (HITL) simulations were conducted using CORSIM to evaluate the expected performance of the customized guidelines before the implementation of the TRPS system and the collection of the "after" data. This approach ensured that all entries in the controllers are correctly programmed and any errors are discovered and corrected in the laboratory before deployment in the field. The HITL setup for Naztec (left) and Eagle controllers (right) is shown in Figure 18.

Figure 18. HITL Simulations to Verify the Updated Databases.

HITL was also used to verify that the appropriate traffic control plans were selected under TRPS mode. The available documentation suggests that TRPS mode will only override the existing Time-Based Control (TBC) when the selected TR cycle length is greater than the TB cycle length, assuming that TR>TBC is entered in the override column of the TBC Traffic Responsive Data Table (ACTRA/MarC-NX). Based on a series of HITL simulations the researchers found that the TR mode always overrides TBC when the Group Mode is set to "Auto" in the MARC Data Coordination data table, as shown in Figure 19.

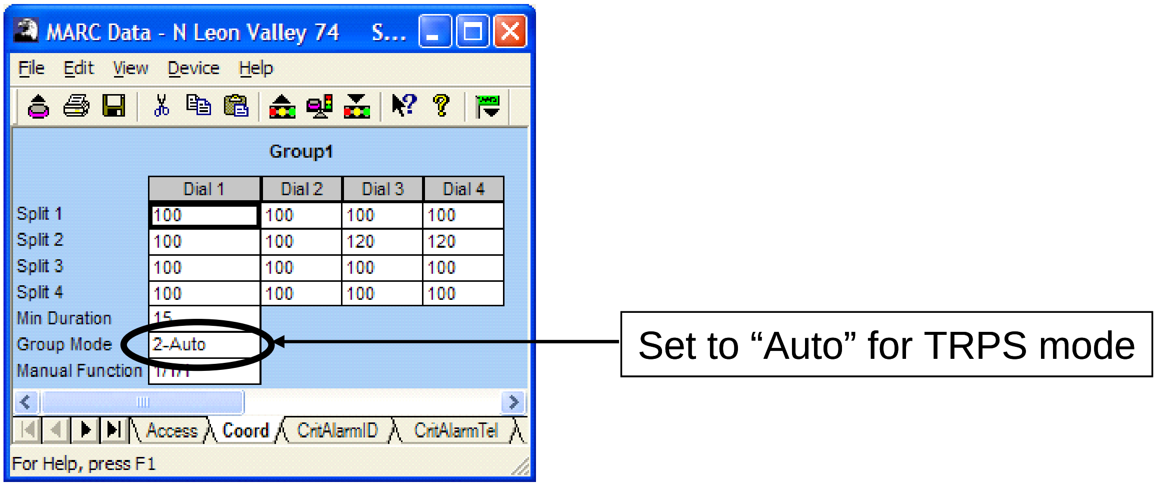


Figure 19. Setting Group Mode in the MARC Data Coordination Table.

Download Updated Databases to Controllers

The research team traveled to all four sites and configured the controllers to operate in TRPS mode by downloading the updated ACTRA or Streetwise databases. Figure 20 shows the database download at one of the controller cabinets in Mexia. The configuration of the controllers and database is illustrated in a step-by-step field manual (Product 5-4421-01-P1) submitted to TxDOT separately.

Figure 20. Database Download.

Verification of TRPS Mode

The TRPS mode of operation was verified at each implementation site by monitoring the status of signal operation at the master and local controllers following the download of the updated database. In the cases of the Mexia and Bellmead sites, system performance data were also obtained by connecting to the master controllers through dial-up connection. System performance data for the San Antonio site were uploaded and emailed to the researchers by Mr. David Smith at the San Antonio District of TxDOT.

MARC Data - N Leon Valley 74 SOURCE : Database

File Edit View Device Help

	Program Day	Hour	Min	Group 1 Pattern	Group 1 TR Override	Group 2 Pattern	Group 2 TR Override
1	1	6	0	1/3/1	1-TR>TBC	Free(OFF=4)	0-None
2	1	9	45	1/3/1	1-TR>TBC	1/1/1	0-None
3	1	11	30	1/3/1	1-TR>TBC	2/1/1	0-None
4	1	12	30	1/3/1	1-TR>TBC	1/1/1	0-None
5	1	15	30	1/3/1	1-TR>TBC	1/1/1	0-None
6	1	17	0	1/3/1	1-TR>TBC	Free(OFF=4)	0-None
7	1	19	0	Free(OFF=4)	1-TR>TBC	Free(OFF=4)	0-None
8	2	4	30	Free(OFF=4)	1-TR>TBC	Free(OFF=4)	0-None
9	2	5	30	Free(OFF=4)	1-TR>TBC	Free(OFF=4)	0-None
10	2	6	45	1/3/1	1-TR>TBC	3/1/2	0-None
11	2	8	30	1/3/1	1-TR>TBC	1/1/1	0-None
12	2	8	45	1/3/1	1-TR>TBC	1/1/1	0-None
13	2	11	0	1/1/1	1-TR>TBC	2/1/1	0-None
14	2	13	0	1/1/1	1-TR>TBC	1/1/1	0-None
15	2	15	30	1/1/1	1-TR>TBC	1/1/1	0-None
16	2	15	45	3/1/1	1-TR>TBC	3/3/3	0-None
17	2	16	0	3/1/1	1-TR>TBC	3/3/3	0-None
18	2	19	30	Free(OFF=4)	1-TR>TBC	1/1/1	0-None
19	2	21	0	Free(OFF=4)	1-TR>TBC	Free(OFF=4)	0-None
20	0	0	0		0-None		0-None
21	0	0	0		0-None		0-None

Access | Coord | CritAlarmID | CritAlarmTel | IntDetAssign | TBCAux | TBC DST & Equates

For Help, press F1

MARC Group Pattern Report

9/5/2006 8:08:29

Master Name: N Leon Valley 74

Report Start: 01/01/2006 00:00:00
Report End: 09/05/2006 08:08:28

Date/Time	Group	Pattern	Source
9/4/06 23:47	1	1 / 1 / 1	1
9/5/06 0:19	1	1 / 3 / 1	1
9/5/06 0:34	1	1 / 1 / 1	1
9/5/06 5:42	1	1 / 4 / 1	1
9/5/06 6:56	1	2 / 4 / 1	1
9/5/06 7:11	1	3 / 4 / 1	1
9/5/06 7:26	1	4 / 4 / 1	1

Figure 21. Verification of TRPS Mode of Operation at the San Antonio Site Using MARC Group Pattern Report.

"AFTER" STUDIES

Travel time studies were conducted at each site after the implementation of the TRPS mode. Data collections during these "after" studies were performed by the same personnel on approximately the same days of the week (between Tuesday and Thursday) using the same method and test vehicle as during the "before" studies. Similar traffic demands were observed during the periods of the "before" and "after" studies. In addition to determining travel times, researchers observed queues on the side streets for average speeds and delays. The travel time studies typically included about 40 runs at each study site.

PERFORMANCE EVALUATION OF THE TRPS MODE

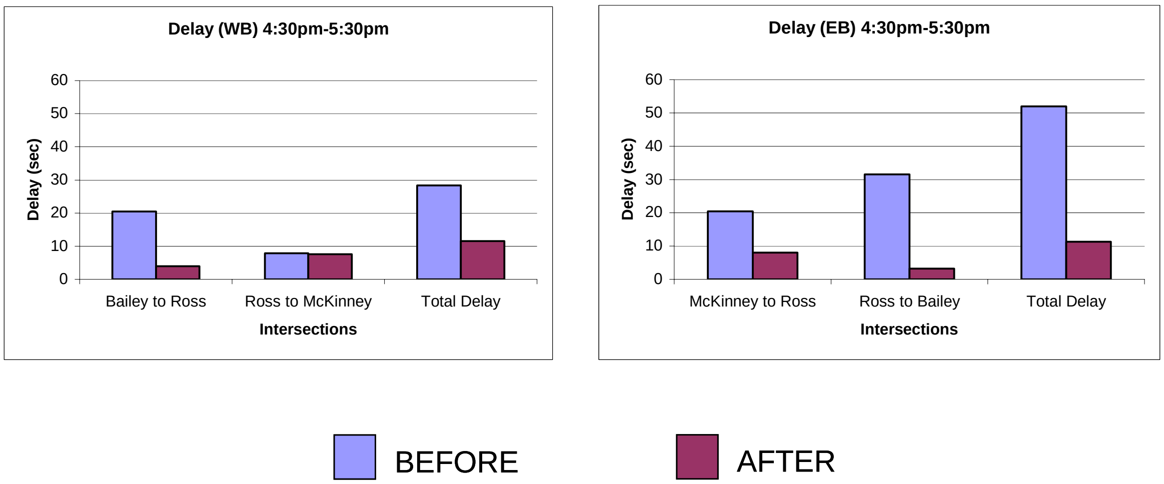
The system performance was evaluated at each site by comparing average delays and speeds determined from the travel time studies conducted before and after the implementation of the TRPS mode. Figure 22 shows the average vehicle delays, average instantaneous speed profiles, and average link speeds during PM peak along the arterial at the Mexia site. The average delays (seconds/vehicle) between intersections and for the entire system are shown in the upper part of the figure. The delay decreased on each segment after the TRPS mode was implemented. The average speed profiles determined from travel time runs in the eastbound and westbound directions are shown in the lower part of the figure. The bold black frames delineate the arterial segments between the three intersections. The average link speeds generally increased after the TRPS mode was implemented. The stops and slowdowns on the approach to the intersections typically decreased under the TRPS mode as indicated by the smoother average instantaneous speed profiles.

Similar performance evaluation was performed for each site. Average delay and speed profiles for the Bellmead site are shown in Figure 23 and Figure 24. The two figures correspond to different routes. Figure 23 shows the results from travel time runs conducted along Spur 299, while Figure 24 shows the delays and speeds along the US 84 route. The average delays and speeds for the remaining two sites are shown in Figure 25 (Waco site) and Figure 26 (San Antonio site). Comparison of the before-after MOEs indicated that the performance of TRPS mode was either better than or comparable to the existing system at each implementation site.

FIELD MANUAL

One of the objectives of this project was to facilitate the implementation of the TRPS guidelines. Therefore, the TTI team prepared a step-by-step field manual to guide field technicians through the process of configuring their controllers to run in the TRPS mode.

Average Delay (sec/vehicle)



Average Speed (mph)

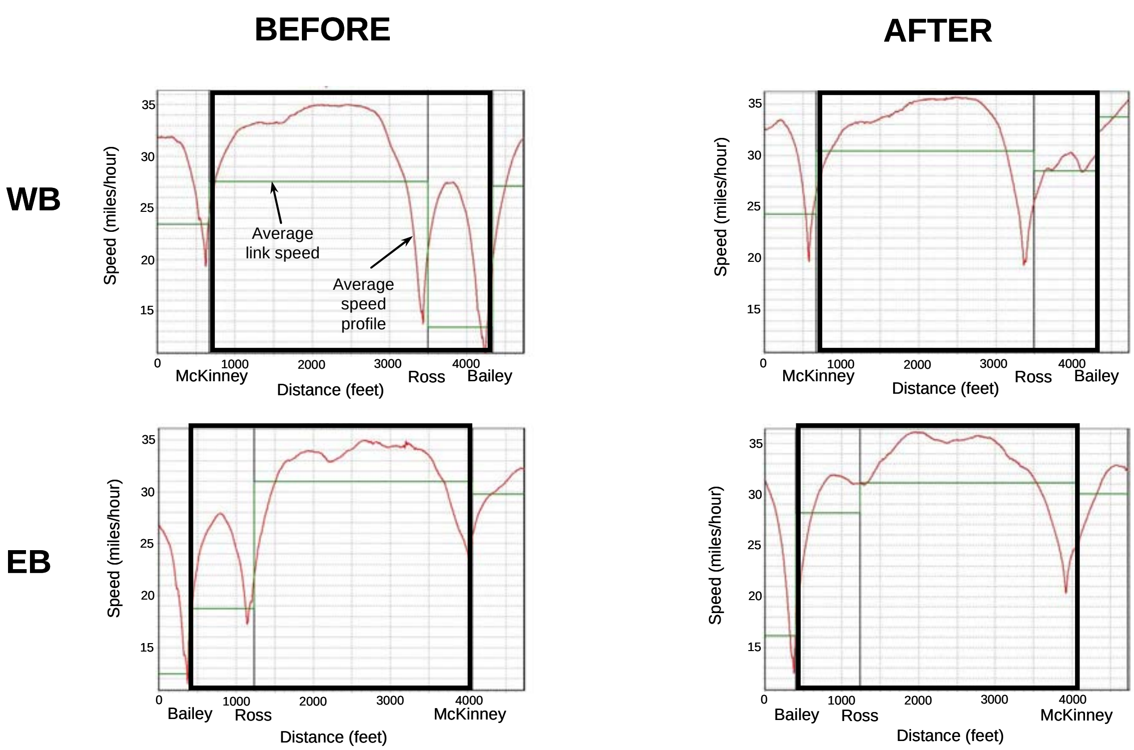


Figure 22. Average PM-Peak Delay and Speed at the Mexia Site Before and After Implementation of TRPS Mode.

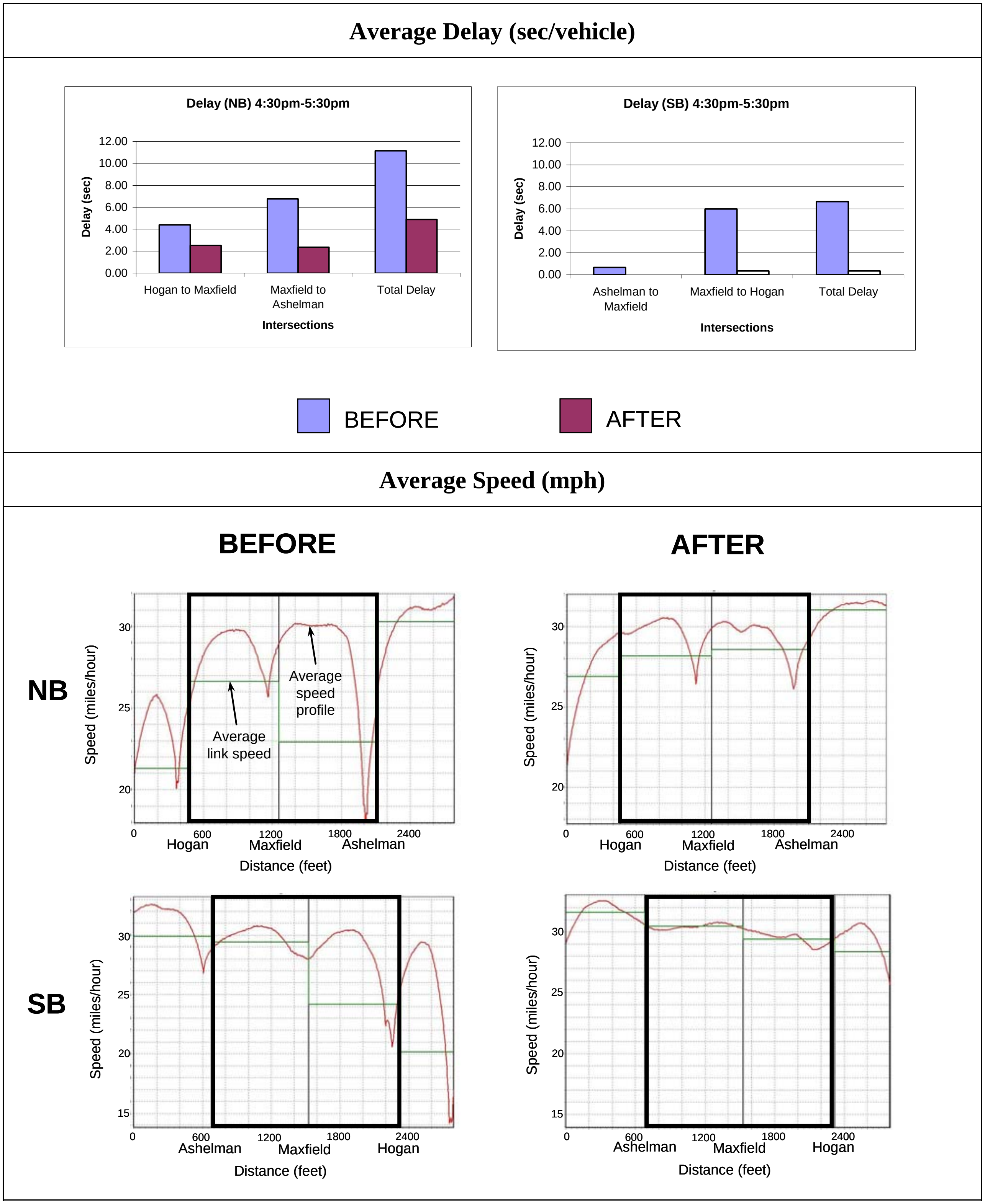


Figure 23. Average PM-Peak Delay and Speed Along the Spur 299 Route at the Bellmead Site Before and After Implementation of TRPS Mode.

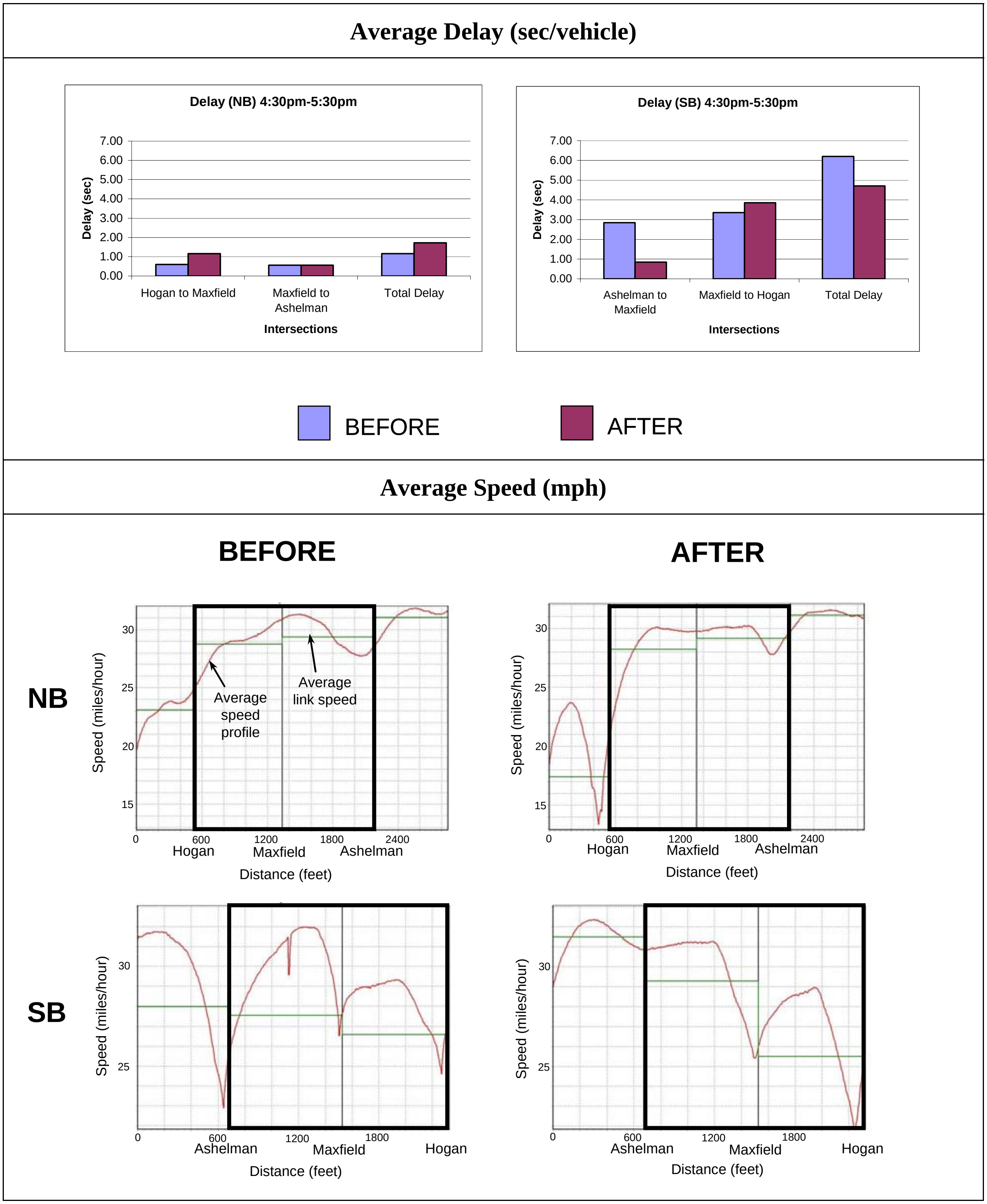
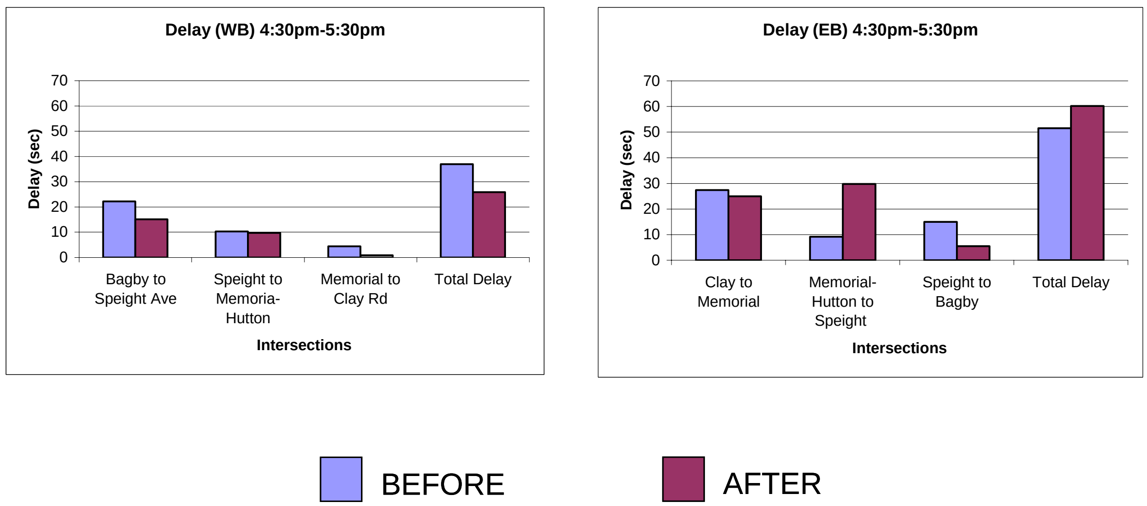


Figure 24. Average PM-Peak Delay and Speed Along the US 84 Route at the Bellmead Site Before and After Implementation of TRPS Mode.

Average Delay (sec/vehicle)



Average Speed (mph)

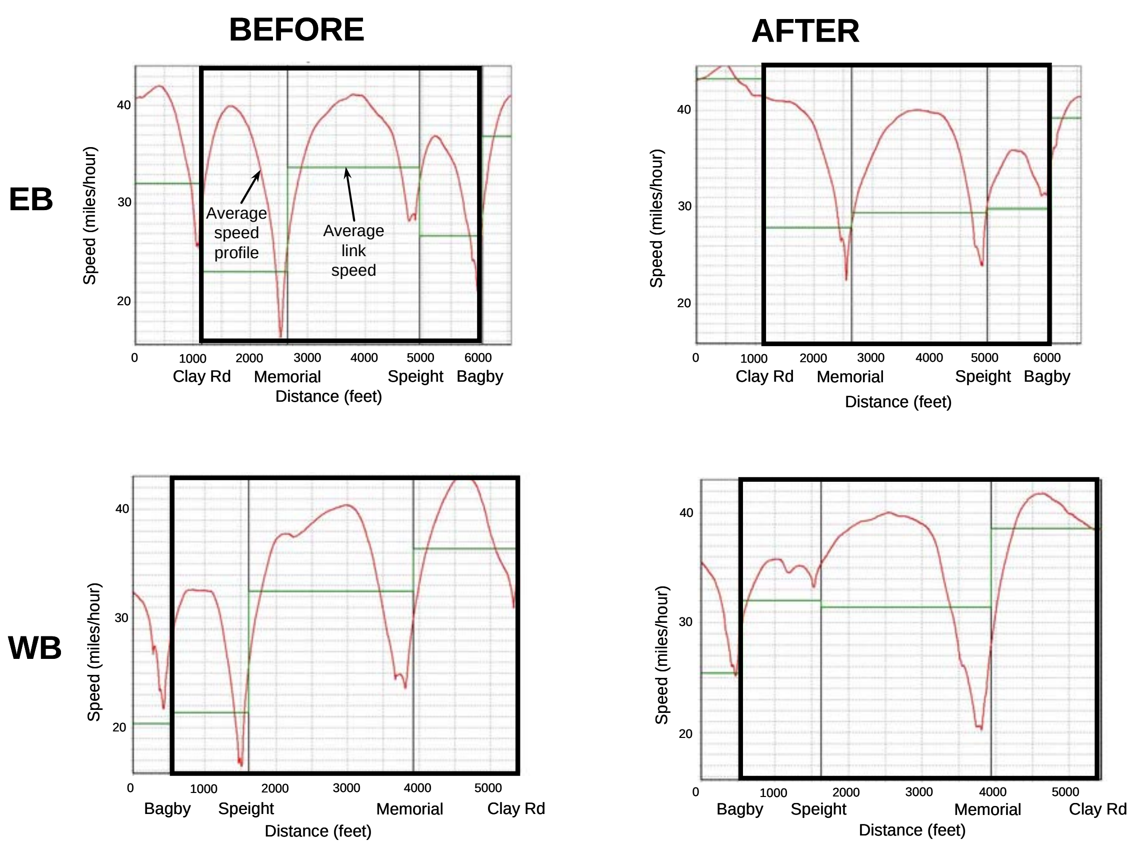


Figure 25. Average PM-Peak Delay and Speed at the Waco Site Before and After Implementation of TRPS Mode.

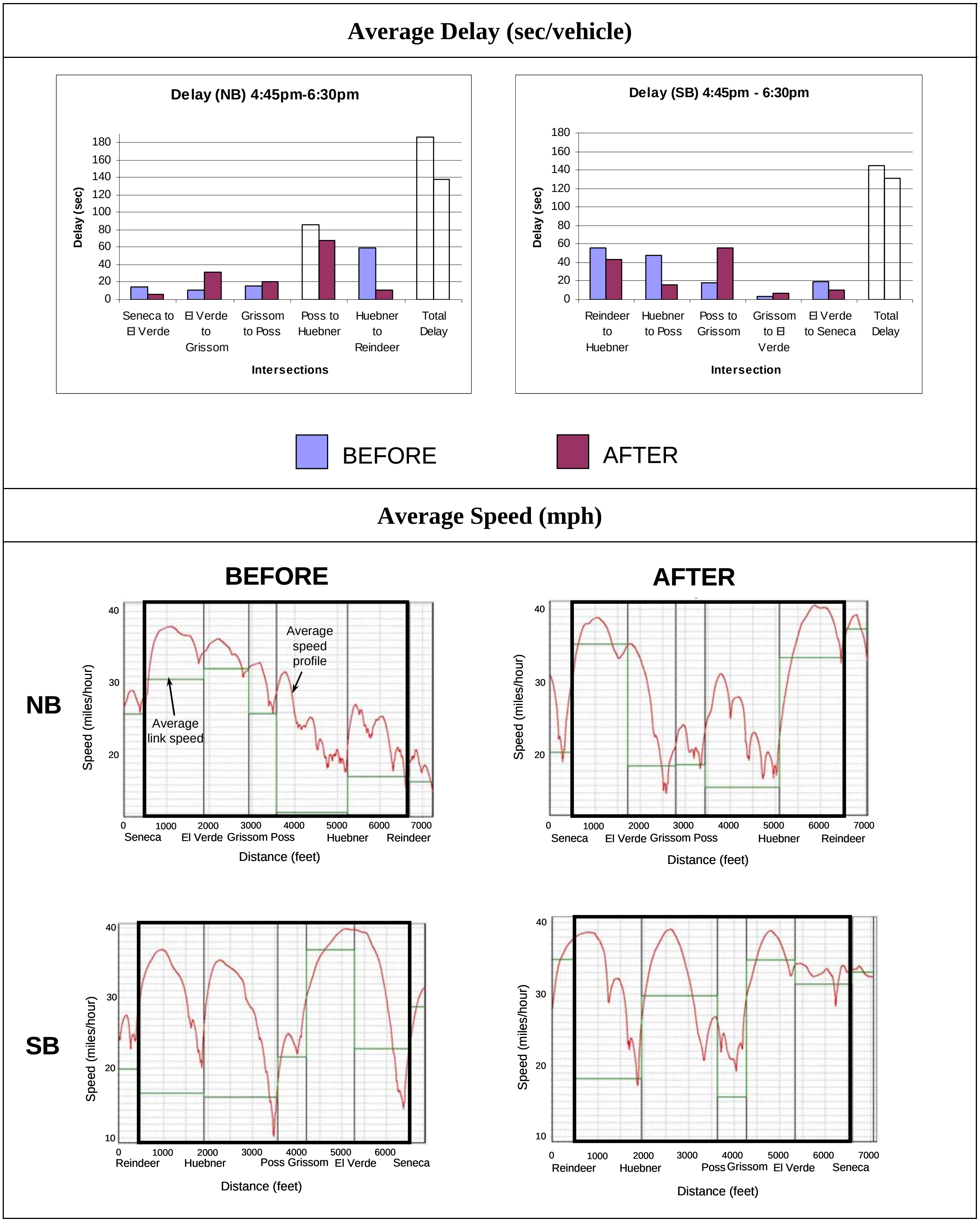


Figure 26. Average PM-Peak Delay and Speed at the San Antonio Site Before and After Implementation of TRPS Mode.

CONCLUSION

This project implemented customized versions of the general guidelines developed in research project 0-4421 at four locations in Texas. Originally six locations were considered, but TRPS could not be implemented at two sites due to problems with wireless communication and system detectors that could not be resolved during the project period. The implementation sites were selected to represent a range of traffic conditions, arterial and detector configurations, and the two common controller types (Eagle and Naztec) used by TxDOT. Customization of the general guidelines developed in project 0-4421 was necessary to account for the differences in certain site characteristics (e.g., available system detectors) between the implementation sites and the closed-loop system for which the original guidelines were developed. Researchers evaluated the performance of the TRPS mode at each site by comparing average travel speeds (instantaneous and link speeds) and delays determined from travel time studies conducted before and after the implementation of the traffic responsive mode. The before-after analyses indicated that the performance of the TRPS mode was in most cases better or at least as good as the existing systems. A step-by-step field manual to guide field technicians through the process of configuring their controllers to run a TRPS control was also developed and delivered to TxDOT.

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