Field Verification of Coordinated Actuated Control

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Actuated traffic signals are used effectively on isolated intersections. By carefully designing controller coordination parameters, actuated control systems can efficiently adjust phase green times and cycle lengths, thereby enhancing arterial coordination. The purpose of the study was to develop an analytical methodology for improving the overall design and operation of actuated controllers, determine the best way to use the added flexibility of actuated control in a coordinated system, and generate feasible coordination parameters for arterial progression. The field examination of the coordinated, actuated operations of a real arterial traffic signal system in Kingsville, Texas, is described. The validity of the simulation study was proven. Significant signal system improvements were observed when semiactuated coordinated timing was used compared with that observed when a either fully actuated or a pretimed coordinated timing plan was used. The study results suggest that significant operational improvements can be achieved through effective coordinated, actuated control.

The traffic industry is witnessing the increasing use of highly sophisticated hardware for controlling signalized systems. Actuated signals can be used effectively in managing isolated, signalized intersections. The present study was performed to develop a reliable analytical methodology for improving the design and operation of actuated controllers, determine the best way to use the added flexibility of actuated control in a coordinated system, and provide recommendations for feasible coordination methods for effective arterial progression.

The current signal timing methods are somewhat inadequate for using actuated equipment effectively to its fullest potential. Simulation studies conducted by the Texas Transportation Institute (TTI) have identified analytical approaches, optimal variables, and recommendations for the proper use in coordinated, actuated control. Specifically, the study was performed to verify the applicability and degree of operational improvements that can be achieved in the field.

Overall, the research has indicated that annual savings of a few million dollars can be obtained even on a medium-sized signal system by using properly timed actuated systems.

STUDY OBJECTIVE

The primary objectives of the field evaluation study were to

1. Verify the operational improvements obtained from the simulation study evaluation,
2. Examine recommended methodology under various coordinated schemes,
3. Quantify the benefits of actuation compared with those of pretimed operation,
4. Identify strategies that can enhance coordinated actuated operation, and
5. Verify the statistical accuracy of the commonly accepted rule-of-thumb observations on different controls in the field.

STUDY BACKGROUND

In an isolated actuated control system the operational performance would depend on traffic patterns and control variables (*1*). Under arterial coordination factors like force-offs, minimum and maximum greens, and vehicle extensions are more important. However, the performance of a signal system is affected not only by signal timing parameters but also by field conditions and location-specific traffic characteristics.

LITERATURE REVIEW

Many researchers have examined the relationship among actuated variables and performance measures (*2*). Lin and Percy (*3*) studied the optimal timing settings and detector lengths for fully actuated signals operating in the presence mode by using the RAPID simulation model. The study suggested maximum greens from an extra 10 sec to 2.5 times of the optimum pretimed split for a peaking factor variation of between 1.0 and 0.7. Kell and Fullerton (*4*) suggested that maximum greens closer to 1.5 times the pretimed split were more optimal.

Tarnoff and Parsonson (*2*) indicated that the performance of fully actuated controllers is superior to that of pretimed controllers at low volumes. At high volumes close to saturation they also indicated that fully actuated control tends to perform worse than pretimed signals. Their conclusions indicate that shorter vehicle extensions close to 2.5 sec are ideal. They also recommended a detector setback of 50 m (150 ft) as ideal in the case of volume density controllers for approaches with traffic above 59 km/hr (35 mph).

Bullen (*5*) suggested that a vehicle extension of 4.0 sec is ideal for single detectors under passage (pulse) mode, regardless of detector location or approach speeds. It should be noted that the model (EVIPAS) used by Bullen considered variable queue discharge headways. This result is important in the case of smaller detector setbacks because of the high likelihood of queues reaching the detectors.

Recently, modifications have been made to some well-known pretimed optimization programs to account for actuated features. An interesting new feature in TRANSYT-7F is the arterial priority option (APO) by Muskaluk and Parsonson (*6*). This new feature allows the option of giving more priority to the arterial while providing a user-selected degree of saturation to the minor movements to constrain performance degradation to acceptable levels (*7,8*).

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However, most previous studies are limited to isolated intersections with certain geometric and phasing combinations. A comprehensive qualitative and quantitative evaluation of coordinated actuated control has not yet been made.

STUDY METHODOLOGY

The study described here compared the field effectiveness of uncoordinated fully actuated, pretimed, and semiactuated timing schemes. In the first stage of the study current signal timings and site characteristics were obtained from the Corpus Christi District of the Texas Department of Transportation (TxDOT). A series of coordinated plans based on these data was developed. Simulation studies were conducted to identify the optimal parameters suitable for both isolated and coordinated actuated operations. Finally, the field experiments were conducted, and the field observations were compared with the corresponding simulation analysis results.

Simulation Study

Results obtained from TRAF-NETSIM and TEXAS models for isolated signal operations indicate that the most important factors that affect actuated signal performance are the vehicle extension and detector setback (*9,10*). In the present study the results from isolated intersections were applied to coordinated signal systems by accounting for the effects of progression and traffic randomness on different approaches.

Study Site

Kingsville, Texas, 80 km (50 mi) south of Corpus Christi, Texas, has a population of 27,000. The main signal system in Kingsville consists of two main crossing arterials, including route US-77 (north-south) and route SH-141 (east-west). These routes carry most of the traffic among the primary traffic generators in the city. The two arterial streets form a T-system.

The traffic signal improvement plans provided by the Corpus Christi District of TxDOT gave necessary information on the geometric layout, intersection spacing, and controller settings, which are illustrated in Figure 1. Figure 2 summarizes the roadway volumes and turning splits for each intersection, which were based on traffic counts made on Tuesday, Wednesday, and Thursday, August 4 to 6, 1992.

There are 12 moderately spaced intersections in the entire system. Seven intersections are located along US-77, four are located along SH-141, and two intersections are located off the two main routes. One intersection on US-77 is five-legged, and all of the other intersections are of the standard four-leg design. Two-way left turn lanes are provided on both major routes for midblock turns. The peak hour falls during the evening, but traffic volumes are almost always well below capacity. The speed limit for the section relevant to the study is 56 km/hr (35 mph), except for a short length at the northern end where the speed limit is 64 km/hr (40 mph). The Kingsville system is running fully actuated control without any coordination. Recently, the signals have been brought under the control of a closed-loop system.

Traffic Volumes

The 15-min time periods were condensed to provide hourly volumes at each intersection separately and combined. The highest total hourly volumes were observed from 4:30 p.m. to 5:30 p.m. Traffic volume patterns remain predictably constant over the same time periods because of the set origin-destination characteristics of vehicle trips in this area. For this reason and because of the availability of very recent volume counts on dates similar to those of the field studies, volume counts were not repeated during the floating car studies.

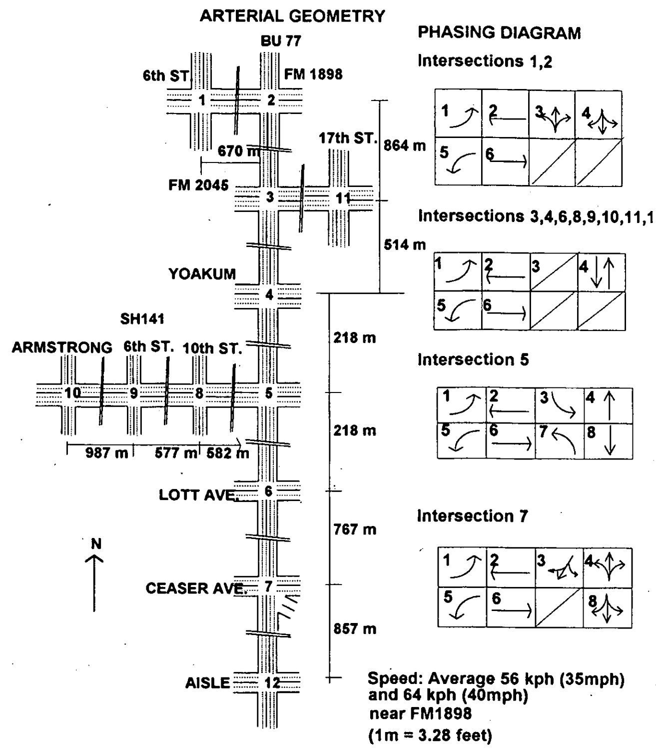


FIGURE 1 System geometry and signal phasing.

Signal Control

Leading left sequence and lead-lag sequence timings were examined to provide optimized pretimed coordination plan, including the proper cycle lengths, splits, and coordination offsets. The optimal PASSER-TRANSYT runs indicated that a cycle length of 70 sec is appropriate for the leading left phase and 75 sec is appropriate for the lead-lag phasing sequence.

The timings and offsets obtained from the combined PASSER-TRANSYT runs were further transformed into force-offs and yield points. The ends of the pretimed splits were set to be the force-offs. Yield point values were based on the end of arterial green from the pretimed offset as the start of yellow for the actuated control. Maximum greens currently set in the field were kept in all the simulation scenarios. Vehicle extensions of 2.0 sec were used consistently on all approaches. This was done in line with previous research studies. The arterial approaches were left on recall.

Simulation Observations

Eight coordinated timing schemes were simulated on the system by using the NETSIM simulation model. The fully actuated uncoordinated timing scheme performed the best among all the cases. This

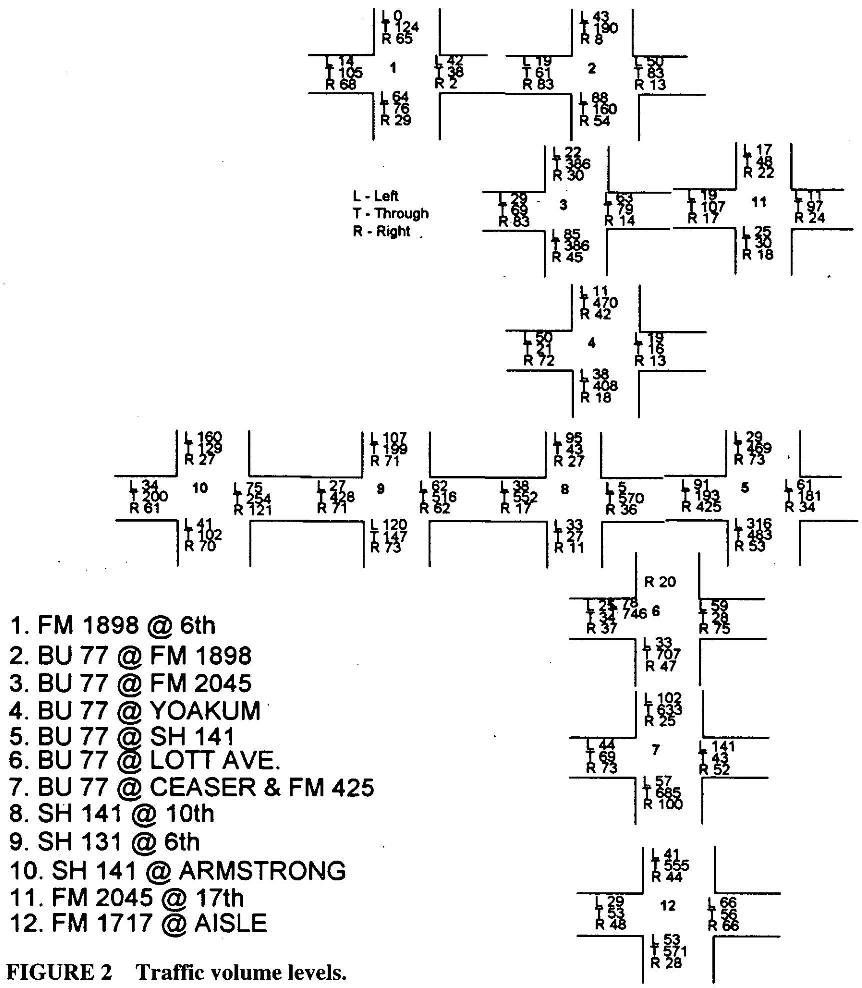


FIGURE 2 Traffic volume levels.

contradicted the usual observation that coordinated operation usually results in better performance. An analysis of the data led to the conclusion that the poor coordination in this specific location resulted from the low traffic volumes, high turn percentages, high mid-block volumes, and long cycle lengths.

To determine whether a coordinated system could be justified at higher volume conditions, the system was analyzed under higher volumes. The entry volumes were increased at the northern and southern ends of Business-77 and the western end of SH-141. These results indicated that the volumes present in the arterial are so low that coordination is actually detrimental. It was concluded from these results that even though field studies were likely to show a reduction in travel times along the artery, they would also show a significant increase in delay on the side streets. This would outweigh the overall benefits that may be achieved through arterial travel time reduction under coordination compared with that under full actuation.

Field Study

The field study was conducted at the Kingsville site December 8, 9, and 10, 1992, in coordination with the operating agencies. The field study was also recorded on videotape.

Field Observation

Field studies performed in Kingsville consisted of two parts: floating car studies and side street delay studies (*11*, p. 96; *12–14*). The floating car studies were conducted by driving a car up and down the street and recording the travel time between each intersection, the stop time at each intersection, and the total stops. All attempts were made for the floating car to match the prevailing travel speed of the traffic stream. FLOATCAR program, developed at TTI, was used to collect the travel time data.

Stopped Delay Study

The stopped delay studies were conducted on the cross street at Lott Avenue by counting the queue at 15-sec intervals, counting the total volume on the approach, and counting the total number of vehicles that were required to stop.

Floating Car Study

The floating car studies can provide a good indication of the arterial progression provided by the system. This is important especially if there is heavy through traffic on the street or if there are high-priority vehicles that travel the street. Stopped delay studies provide a good indication of what expense the side street traffic is required to pay to have progression on the arterial.

To achieve an optimum solution one must weigh the relative benefits of stops, delays, fuel consumption, and so on as well as the importance of the artery to the side street. In the present study it was assumed that the side street traffic is equal in importance to arterial traffic.

Nine control strategies were carefully examined in the field experiments conducted December 8, 1992 (Tuesday) through December 10, 1992 (Thursday) in Kingsville. During the field studies three timing scenarios were tested per day during the noon peak [11:00 a.m. to 1:00 p.m. (NOON)], evening early peak [4:00 p.m. to 5:00 p.m. (PM-1)], and evening late peak [5:00 p.m. to 6:00 p.m. (PM-2)]. The time periods and case descriptions of the 3-day study follow.

- Case 1 (December 8, 1992, NOON): Full-traffic actuated running free (currently used by TxDOT),
- Case 2 (December 8, 1992, PM-1): Semi-traffic actuated coordinated with a 100-sec cycle length,
- Case 3 (December 8, 1992, PM-2): Full-traffic actuated running free (Currently used by TxDOT),
- Case 4 (December 9, 1992, NOON): Three intersections (King, Lott, and Ceaser) operating 55-sec semiactuated with the rest of the four signals operating free,
- Case 5 (December 9, 1992, PM-1): Semi-traffic actuated coordinated with a 70-sec cycle length,
- Case 6 (December 9; 1992, PM-2): Pretimed coordinated with a 70-sec cycle length,
- CASE 7 (December 10, 1992, NOON): Semi-traffic actuated coordinated with a 55-sec cycle length,
- CASE 8 (December 10, 1992, PM-1): Semi-traffic actuated coordinated with a 55-sec cycle length, and
- CASE 9 (December 10, 1992, PM-2): Semi-traffic actuated coordinated with an 80-sec cycle length (TxDOT early return strategy).

The indicated case numbers are used to refer to the corresponding timing schemes in further discussions. This schedule was determined after weighing various factors, such as the cases that would provide appropriate scenario pairs while conducting statistical analyses.

Control Strategies

The control strategies presented earlier can be classified into four groups based on the different analysis methodologies used to develop the signal timing parameters used in the study.

TxDOT PASSER-Based Semiactuated Timing Schemes Timing Cases 2 and 9 were obtained through PASSER II-90 analysis by the Corpus Christi District Office of TxDOT. These runs were made to improve overall arterial progression. The original run produced a 100-sec cycle length. The program produced an 80-sec cycle length solution after modifications were made to the data set to account for actuated control.

PASSER-TRANSYT-Based Pretimed and Semiactuated Timing Schemes To further improve the PASSER II timing the Kingsville system was analyzed by TRANSYT-7F with an attempt to minimize delay and stops. A 70-sec cycle length was obtained, which was used in Timing Cases 5 and 6.

Minimum Delay Cycle Length-Based Timing Schemes The examination of PASSER II-90 output indicated that the minimum delay cycle length at a number of intersections was in the range of 55 sec. This led to the conclusion that actuated controllers would provide superior operation if they were coordinated with a 55 sec cycle length. This system was designed with TRANSYT and tested as Timing Cases 7 and 8.

Volume-to-Capacity Ratio-Based Timing Scheme Further study of the output indicated that the volume-to-capacity (V/C) ratios ranged from 15 to 60 percent. It was suspected that the fixed coordinated cycle lengths could not compete against fully actuated control at intersections operating below 40 percent. Thus, a new timing scheme that concentrated on coordinating signals operating above a 40 percent V/C ratio was produced. In this solution King, Lott, and Caesar along 14th Street were coordinated. Although Lott Avenue operates below the specified V/C level, it is included because of its location between two intersections that operate at much higher V/C ratios. This resulted in Timing Case 4.

Field Data Processing

The floating car data collected were manually examined to detect any data entry errors. The comments entered during data collection were incorporated into a data file. The data were further processed by using FLOATPRO, a postprocessor to the FLOATCAR program, to summarize the information and to provide travel times and stopped delay in a form that could easily be analyzed.

Statistical Analysis

The results obtained from the field study were analyzed by statistical techniques to assess the significance of the arterial travel time, side street delay, and stop results. A level of significance of 5 percent was used consistently.

Travel Times

Analysis of the collected travel time data indicated that the average difference in travel speeds was between 3.2 and 6.4 km/hr (2 and 4 mph). The average range in travel speeds was 16 km/hr (10 mph). The approximate minimum sample size requirement for travel time and delay studies for travel speeds of between 4.0 and 16.0 km/hr (2.5 to 10.0 mph) is two to four runs [with a confidence level of 95.0 percent and a possible error of 3.2 to 8 km/hr (2.0 to 5.0 mph)]. These criteria were satisfied in travel time studies.

Paired *t*-tests were conducted on the travel time data for the various pairs of scenarios to verify the statistical significance of the results. For the sake of clarity, tests were done in three groups, to answer the corresponding questions.

- Group 1. Is there a statistically significant difference between the mean travel times of the pair of scenarios under examination?

• Group 2. Is there is a statistically significant decrease in the mean travel times in the second scenario (of the pair under examination) compared with that in the pretimed scenario?

• Group 3. Is there is a statistically significant decrease between the mean travel times in the semiactuated timing scenarios under examination?

Performance Evaluation

The system performance evaluation was made by statistically comparing the arterial travel times, side street stop delay values, and the total number of stops during each control strategy, as observed during the field studies.

Side Street Stopped Delay The side street delay observations were compared for significant differences. The evaluation was made by comparing the 95 percent confidence intervals of all the observations.

Arterial Stops The stop values obtained from FLOATPRO were analyzed by using *t*-tests for equality or difference between the means for samples, assuming different variances among different control strategies. The analysis was kept in line with the pairs of cases used for travel time analysis. The tests for the number of stops were conducted for a 5 percent level of significance.

The average and variance of the number of stops in each scenario were first obtained. The *t*-tests were then conducted for measuring the difference in means (assuming unequal variance) for the appropriate pairs. These groups of tests were conducted at a 5 percent level of significance for the north-south direction, the south-north direction, and for both directions combined. For the sake of clarity only the results from both directions combined are given in this paper. The tests could be classified into the following three groups, which attempted to answer the corresponding questions.

• Group 1. Is there a significant difference in the mean number of stops in the pairs of scenarios considered?

• Group 2. Is there a significant decrease in the mean number of stops in the first scenario compared with that in the pretimed scenario, which was kept as the second component?

• Group 3. Is there a significant decrease in the mean number of stops in the first scenario compared with that in the second scenario (in which one or more of the pair of cases was semiactuated)?

Study Results

The most interesting observation from the field study was the closeness of field estimates of total delay and the NETSIM simulation results. Figure 3 provides the total system delay as given by NETSIM and the corresponding field estimates. The percentage difference was compared against pretimed operations during the p.m. peak periods. As shown in Figure 3 the close trend is remarkable, which strongly indicates the validity of the overall simulation results. The minor differences found were due to lower volumes during the afternoon period. The consistency of simulation results may imply the usefulness of NETSIM for similar studies in the future. The statistical analysis results for arterial travel time, side street delay, and stops are given in the following paragraphs.

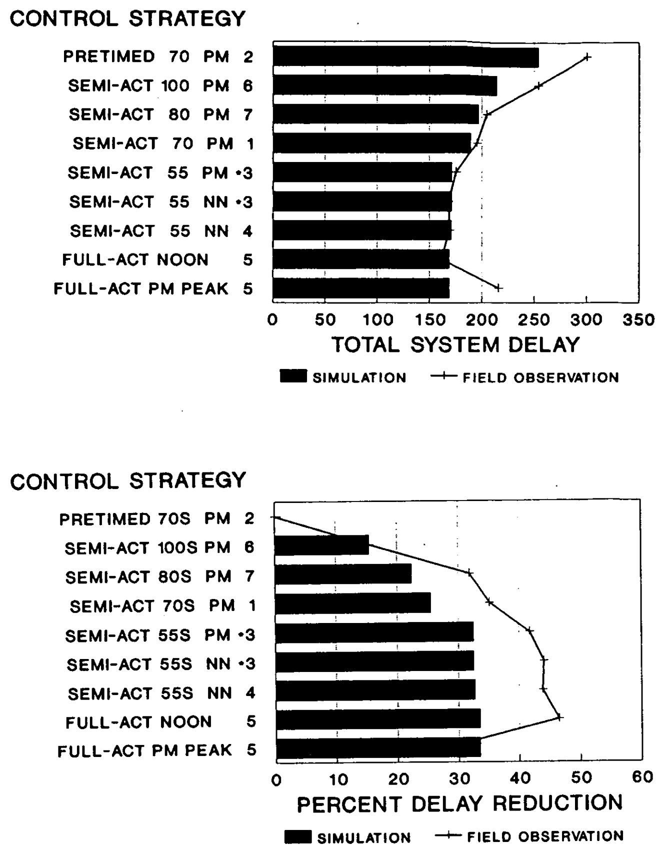


FIGURE 3 Simulation versus field study

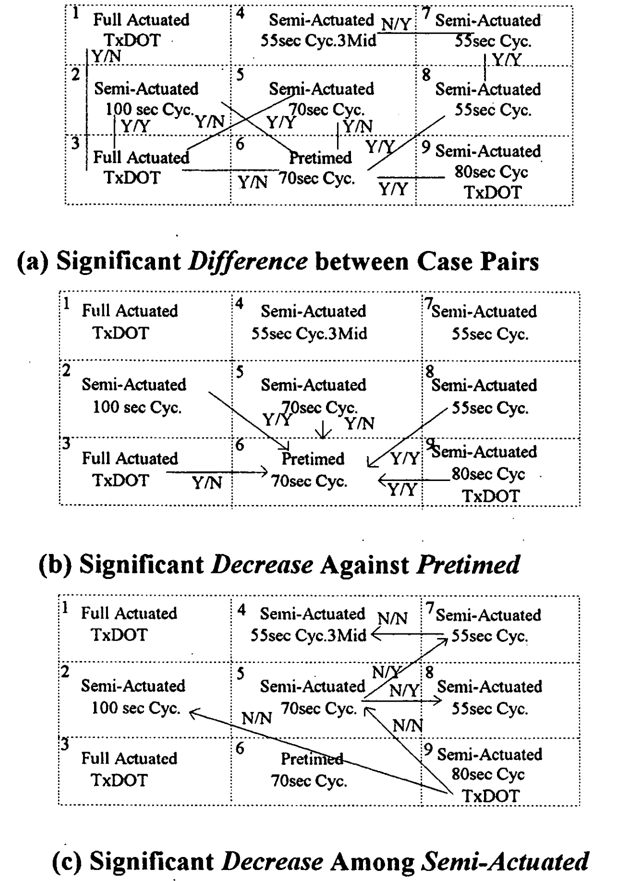
Travel Times

In both the directions, the pretimed 70-sec cycle scenario resulted in the worst travel time performance. In the northbound direction the best travel times were observed for the semiactuated 100-sec cycle scenario. The semiactuated 80-sec cycle length case produced the second best travel time. This is expected because of the increased bandwidth size provided by the longer cycle lengths.

In the southbound direction, the best case was the scenario of semiactuated 55-sec cycle (noon) with all signals coordinated. In this direction coordinated operation with higher cycle lengths provided better travel times through the arterial. However, in the southbound direction the travel times were greatly affected by the heavy left turn volume onto SH-141 opposing the southbound arterial movement. Hence, during periods of lower left turn volumes (noon), better southbound travel times were observed.

The fully actuated timing plans resulted in some of the worst arterial travel plans in both directions. This is primarily because of the lack of progression when the arterial is running free. The differences among the estimated mean travel times of the various coordinated actuated timing schemes are less than 30 sec (<10 percent). Since there is relatively little through traffic, the slight increase in arterial delay may be acceptable if side street delay is decreased.

Figure 4 indicates the statistically significant results between case scenario pairs. The statistical tests were conducted in three sets. The first set of results [Figure 4 (*a*)] indicates whether the corresponding case pairs have any significant difference. The second group



x/x *indicates the result of Paired t-test for north-south & south-north directions*
Y *indicates a significant difference between the means at* $\alpha = 0.5\%$
N *indicates no significant difference exists between the means at* $\alpha = 0.5\%$
Number on the top-left cell indicates the serial number of the scenario.

FIGURE 4 Travel time analysis.

[Figure 4 (*b*)] of comparisons indicates whether there is any significant decrease in travel times compared with those of the pretimed 70-sec cycle (Case 6) scenario. The third group [Figure 4 (*c*)] of comparisons indicates whether there is a decrease in travel time among semiactuated case scenarios.

The results from the second set [Figure 4 (*b*)] clearly indicate that in all cases the pretimed 70-sec cycle (Case 6) operation resulted in the worst performance in the southbound direction. In the other direction, except for two cases (Cases 3 and 5) the pretimed performance was significantly worse. The third set of results [Figure 4 (*c*)] indicates that most of the semiactuated scenarios did not show a significant decrease in travel time compared with those of any of the other semiactuated scenarios.

Side Street Stopped Delay

The mean side street delay values obtained from the stopped delay study at Lott Avenue are shown in Figure 5. The results indicate that there are significant differences in the side street stopped delay among various coordinated schemes. As was expected the side street delay increased with increasing cycle lengths.

The smallest delay value was observed during fully actuated timing during the afternoon peak. There was a significant increase in side street delay between fully actuated timing in the afternoon (Case 1) and fully actuated timing in the evening (Case 3). This was due to the longer cycle lengths created by the heavy evening peak traffic. The 70-sec-cycle-length cases (Case 5 and Case 6) produced side street delays that were not significantly different from that of the fully actuated timing scheme in the evening (Case 3).

The semiactuated 55-sec cycle timing schemes (Cases 4, 7, and 8) produced delays almost identical to each other at different times during the day. The delays observed in such cases were almost equal to the delays during the fully actuated operation (Case 1 and Case 3), which was observed to be running with a similar average cycle length. The average side street delay during the pretimed 70-sec-cycle-length (Case 6) timing scheme was slightly less than that of the semiactuated 70-sec cycle (Case 5) timing scheme because of the longer effective splits provided to the side streets in pretimed control.

Semiactuated operations with 80- and 100-sec cycles produced higher side street delay than the other timing schemes. In view of this and because this system had relatively low through arterial traffic, the ideal timing plan for this system would be a plan of shorter cycle length.

Stops

The stop study results are summarized in Figure 6. Figure 6 can be divided into three parts. The first set [Figure 6 (*a*)] shows the significant stops among case scenarios. These results show the pairs of scenarios in which a statistically significant difference was observed. The second set [Figure 6 (*b*)] shows the cases with a statistically significant decrease in the stops against the pretimed coordinated scenario. The third set [Figure 6 (*c*)] shows the statistically significant decreases among the semiactuated scenarios.

Compared with the pretimed scenario [Figure 6 (*b*)], all cases except the fully actuated scenario (Case 3) exhibited a decrease in the number of stops. Comparisons among semiactuated strategies [Fig-

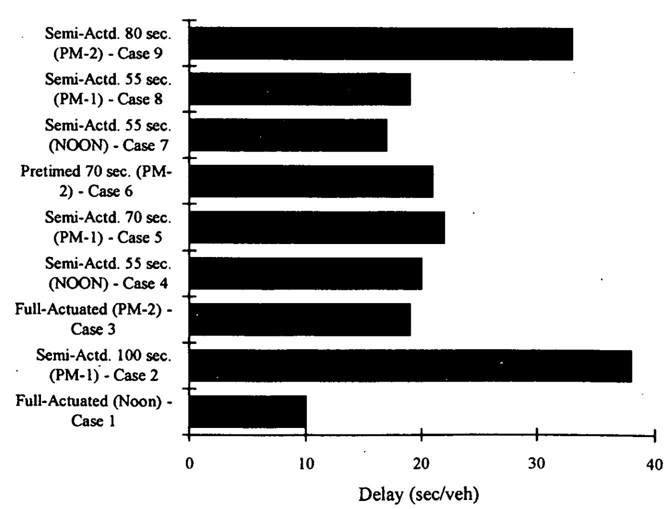
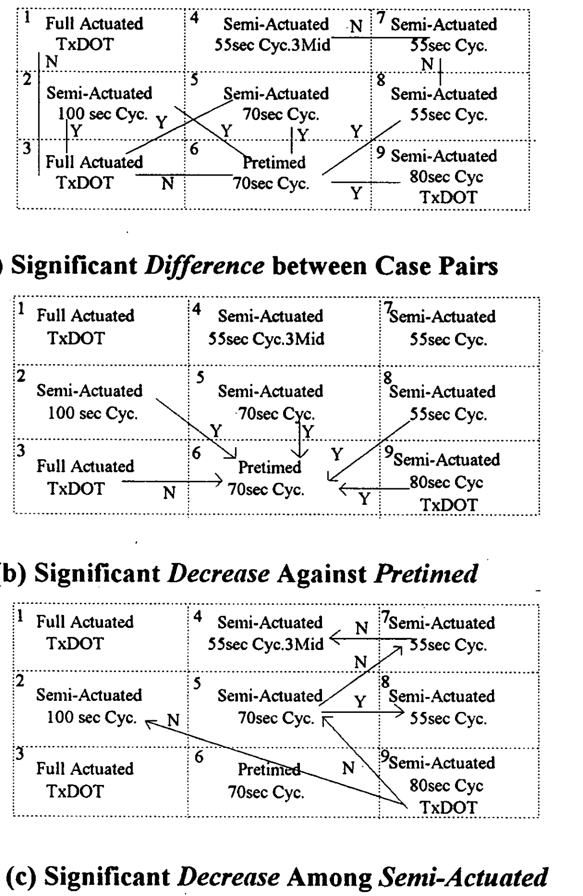


FIGURE 5 Side street delay.

ure 6 (*c*)] showed that in most cases this strategy indicated a negative result. This implies that the exact semiactuated timing scheme used had little effect on arterial stop performance as long as the basic timing schemes were developed by the recommended methodology. The semiactuated 70-sec cycle (Case 5) scenario resulted in a very stable operation in the field. In travel time and stop evaluation the semiactuated 70-sec cycle (Case 5) performed close to the minimum delay cycle length in the system. Even though the semiactuated 55-sec cycle (Case 8) resulted in the lowest overall system delay, it sometimes resulted in unstable operation and exhibited less resilience to volume variations than the semiactuated 70-sec cycle (Case 5) did.

Overall, it can be observed from Figure 6 that almost all semiactuated strategies performed well when compared with the performances of the pretimed and fully actuated timing scenarios. In addition, higher cycle lengths decreased the number of stops. Shorter cycle lengths of 55 sec showed a definite improvement with respect to stops over the pretimed scenario, but did not perform significantly better than other semiactuated cases with longer cycles.



x *indicates the result of Paired t-test for directions combined*
Y *indicates a significant difference between the means at α = 0.5%*
N *indicates no significant difference exists between the means at α = 0.5%*
Number on the top-left cell indicates the serial number of the scenario.

FIGURE 6 Statistical analysis of stops.

CONCLUSIONS AND RECOMMENDATIONS

The field study was designed to demonstrate the operational effectiveness of using coordinated, actuated control. The Kingsville signal system is a very typical urban arterial in many cities with low to medium volumes throughout the United States. This exercise was later repeated for a high-volume urban arterial located in Fort Worth, Texas, and similar results were obtained.

Conclusions

There was an impressive operational improvement when semiactuated coordinated timing was used compared with that when either full actuation or pretimed coordinated timing was used. No significant differences in stops were observed among the semiactuated cases. However, it was observed that longer cycle lengths would cause higher overall system delays. The following points were observed from the overall simulation and field control experiment:

1. Semiactuated timing schemes can produce significant operational improvements based on both delay and stops evaluation compared with fully actuated and pretimed timings.
2. There are no significant differences in performance among all the semiactuated operations as long as the progression-based arterial signal coordination timing scheme was developed correctly.
3. It was verified that the use of longer coordination cycle lengths generally caused less arterial stops. However, the uses of longer cycle lengths may also generate much higher overall system delays.

Recommendations

Several strategies are available for improving high-speed urban arterials through coordinated, actuated signal operations, such as those used in Kingsville, Texas. Significant improvements can be achieved in the field. However, the achievable effectiveness depends on proper detector configuration, delay settings, actuated timing parameters, and coordination settings. The simulation methodology is recommended as a standard evaluation procedure for considering system adaptability to take advantage of existing arterial signal control equipment in the field.

The early return during actuated operations may create additional progression opportunities. Although all design issues have not been fully investigated, the proper solution appears to optimize offsets by forcing side street splits to some target values. The controller splits during early return can be used by applying a hold to the arterial through phase when platoons are expected to arrive. Other phases can be forced off to provide a guaranteed green for arterial progression. This design could also minimize long delays that are created by arterial gap-outs that take place just before a platoon arrives.

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