Abridgment

Comparative Analysis of Left-Turn Phase Sequencing

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ABSTRACT

Guidelines for left-turn phase use do not generally include recommendations for left-turn signal phase sequence patterns. In this research, the TEXAS simulation model is employed to study the effects of various left-turn sequence patterns on traffic operations in order to establish guidelines for using most typical sequence patterns. Recent literature on the effects of left-turn sequence patterns on intersection delay and accidents is reviewed. Using vehicular delay as a basis for comparison, protected only and protected/permissive left-turn phasing with pretimed control are studied. Dual leading and dual lagging left-turn phase sequences, supplemented by permissive turning and pretimed control, are also studied. Furthermore, split, dual, and composite sequences are compared for the pretimed case. The examination of basic phase sequencing schemes under actuated signal control essentially duplicates that for pretimed control. Finally, guidelines for the implementation of phase sequence patterns are presented.

When left-turn demands approach or exceed maximum unprotected flow rates at signalized intersections, traffic control schemes are usually modified to provide protected left-turn signal phases. Guidelines for left-turn phase use do not generally provide a specific rationale for choosing among the many possible left-turn signal phase sequence patterns. The study reported in this paper (1) contains a description of the effects of various left-turn sequence patterns on left-turn as well as total intersection traffic operations. Guidelines for using most typical sequence patterns are presented.

For the purpose of this discussion the following terminology has been adopted for describing left-turn phase sequences. A protected left-turn phase is that portion of the signal cycle in which left-turn maneuvers are permitted and all conflicting maneuvers are prohibited. A permissive left-turn phase is that portion of a cycle in which left turns are permitted but only through gaps in the opposing traffic stream. A protected left-turn phase that occurs before display of the opposing through green is called a leading phase, and one occurring immediately after the opposing through green is called lagging. The term "dual left turns" is used to describe protected left-turn phases that occur simultaneously on opposing approaches of the same street. "Split phasing" is used to describe schemes in which protected left-turn phases on the same street do not occur simultaneously. Such schemes may or may not use protected left-turn phases on both approaches, and, where present, the protected lefts may occur before, after, or during through movement green indications.

PREVIOUS RESEARCH

Published research findings were reviewed to provide a background for primary data collection and analysis efforts. Five significant references, which dealt with the question of how left-turn phase sequencing affects vehicular delay and accidents, were located (2-6).

Each of these studies compared measures of vehicular delay for protected-only and protected/permissive left-turn phasing. Particular phase sequence patterns such as dual and split arrangements were not specifically addressed. Field studies conducted in Maryland, California, Florida, and Kentucky found that intersection delay was reduced when permissive left-turning supplemented the protected phase.

All of the studies compared the frequency of left-turn accidents before and after permissive phasing was installed. Experiences in the four states indicated that permissive phasing does not produce statistically significant changes in accident experience or accident severity at locations with good geometrics and approach speeds less than 45 mph.

COMPARATIVE ANALYSES

Left-turn phase sequence patterns, using both pretimed and actuated signal controllers, were compared under a variety of traffic demands. Computer simulation using the TEXAS model for intersection traffic was the primary data collection tool. Simulation provided a means of systematically examining combinations of geometry and traffic demand that were of specific interest.

Protected Versus Protected/Permissive Phasing

The first experiment conducted as part of this study compared total delay for permissive/protected and protected left-turn phases with fixed cycle and phase durations. Test conditions were imposed on a four-leg intersection in which all approaches were loaded by the same traffic volumes with a left-turn percentage of 20. The application of different traffic demands to one timing plan demonstrates the set of conditions that might exist through the various peak and off-peak hours of a typical day.

Total vehicular delay was compared for the protected-only and the permissive/protected phase patterns. The nonparametric Kolmogorov-Smirnov test was used to evaluate the statistical significance of the differences in delay statistics. The two test conditions were found to be significantly different at all volume levels, with permissive/protected phasing producing less delay. The protected/permissive sequence generally produced an 80 percent reduction in total delay to left-turn traffic.

The consistency of the delay reduction is particularly significant because opposing traffic volumes ranged from 360 vehicles per hour (vph) (80 percent of 450 vph) to 600 vph (80 percent of 750 vph). Under the low-volume condition, the unprotected left-turn capacity exceeded the demand whereas under the 750 vph demand the unprotected capacity was less than one-third the demand. Therefore, even when a relatively small fraction of the total left-turn demand can be served by a permissive phase, large savings in left-turn delay can be expected.

Phase Sequences Under Pretimed Control

In the previous section permissive/protected phasing was shown to be generally effective in reducing vehicular delay relative to protected-only phasing. The sequence in which protected phases are provided may also have an effect on vehicular delay because most protected phase sequences may be supplemented by permissive turns.

Dual Left-Turn Phasing

Dual leading and lagging left turns were compared under conditions of protected-only left turning. This experiment used the same intersection geometry, signal timing, and traffic demands as the previous experiment. Eight hours of simulated observation time were collected for each test condition. Statistical testing of the differences in total delay between leading and lagging dual phases under protected-only phasing indicates that the two schemes are not significantly different with regard to both left-turning and total approach traffic delay.

Because of this conclusion, vehicular delay and other operational statistics were compared for leading and lagging dual left-turn phasing when both were supplemented by permissive turning. The test conditions were expanded to encompass a variety of 20 different approach traffic demands. For each case, signal phase and cycle lengths were arranged to be nearly optimal for the stated demand and at least 1 hr of simulated observation time was collected.

Nonparametric statistical testing indicates that dual leading left-turn phases produce less delay to left-turning vehicles than does dual lagging if the opposing traffic demand on two inbound lanes is less than approximately 600 vph. When opposing volumes are relatively small, significant numbers of vehicles can execute left-turn maneuvers during the permissive portion of the signal cycle. As opposing traffic volumes increase, the numbers of left turns made during permissive phases decrease until the only opportunities may occur during clearance intervals. As indicated previously, dual leading and dual lagging sequences tend to produce equivalent left-turn delays when very few turning opportunities are available during permissive green intervals. Therefore, dual leading phasing apparently provides more efficient use of unprotected left-turn phase.

Dual Versus Split Phasing

Split left-turn phasing schemes were earlier identified as any of a family of phase sequencing arrangements in which protected left-turn phases on two approaches of the same street do not occur simultaneously. Split phasing is used most effectively on a street where the maximum left-turn and through movement demands occur on the same approach. Thus, both the left-turn and through movement volumes on the opposite approach would be noncritical if both approaches were serviced by a common signal phase. This situation would be particularly appropriate for split phase sequencing with no permissive turning. Ideally, if permissive turns are to be allowed, the left-turn demand on one approach should require more processing time than the through movement, and on the opposing approach more green time should be required to process the through movement.

To compare vehicular delay resulting from dual and split phasing a series of specially designed experiments was conducted. Two nearly optimal signal timing schemes were developed for a traffic demand condition on a four-by-four intersection. In one scheme dual leading left-turn phases were imposed, and in the other, split left-turn phasing was used; permissive left turns were allowed in both. As expected, the dual left phasing produced significantly less left-turn and total intersection delay. This effect can be attributed largely to the shorter phase and cycle lengths possible with dual sequencing.

To extend the comparison and examine the effects of cycle length, the same traffic demands were used again but signal cycle lengths of 60, 80, and 150 sec were used for both the dual and the split sequences. The number of phases required for the 60-sec cycle was the same as in the optimum cycle experiment, and the results were the same.

For the 150-sec cycle, the much larger red times produced larger queues and requirements for protected left-turn phases on all four approaches. Here again, dual left-turn phasing should be better than split phasing because on both streets each approach required more time to process the main street traffic than the left-turn vehicles. The experimental results confirm this conclusion.

The 80-sec cycle, on the other hand, produced requirements for protected left-turn phases on both approaches of street A, but only one approach of street B. In this case, split phasing resulted in less total approach delay on street B, and dual phasing performed more efficiently on street A. The experiments comparing dual and split phases under pretimed control indicate that split phase sequencing should be considered as a candidate sequencing scheme where (a) the critical left-turn and through movement demands occur on the same approach, and (b) on only one approach the required left-turn processing time exceeds that for the through movement.

Phase Sequences Under Actuated Control

A testing program for left-turn phase sequencing under actuated signal control was designed to parallel that for pretimed control. A number of questions regarding detector patterns and controller timing were also studied to provide results comparable with those of the previous experiment.

Detector Configuration and Phase Timing

Sensitivity analyses along with supplemental studies of detector configurations were used to develop plans for detector configuration and phase timing. These studies, in conjunction with consideration of the traffic demands to be studied, yielded initial specifications of 90-ft-long presence detectors in the left-turn bays and across both through traffic lanes. The detectors were set back 10 ft from the stop lines.

One-second initial intervals and 1-sec vehicle extension intervals were used with 2-sec minimum greens. In all experiments permissive left turns supplemented protected left turns. Although the experiments were conducted with fully skippable phases, all phases occurred consistently on both streets. At least 20 min (and up to 90 min) of simulated observation time were collected for these traffic volume cases.

Dual Left-Turn Phasing

Operational efficiency, with vehicular delay as the principal measure of effectiveness, was compared for leading and lagging dual protected left-turn phasing when both were supplemented by permissive left turns and timed by an actuated controller.

Nonparametric statistical tests of the experimental results indicate that dual lagging left-turn phasing creates shorter cycle lengths that produce smaller delays to the dominant through movements. The main street green is used much more effectively with lagging left-turn phases because vehicles in the left-turn queue can be proceeded during gaps in the main street traffic. A leading left-turn phase, on the other hand, may process the entire left-turn queue before the main street green. Therefore, the main street green is used to process only those left-turn vehicles that arrive while it is in progress. As a result, the cycle length for the intersection is increased. In situations where the maximum phase extension is reached during the protected left-turn phase, with dual lag phasing the cycle length will be equal to or shorter than it will be with dual lead phasing.

As the statistical tests also verify, the reduction in cycle duration due to lagging phases causes a significant reduction in delay to through vehicles. Left-turn vehicles benefit from this delay reduction, but at the same time experience a delay increase caused by slower queue dissipation. Thus, left-turn vehicles may or may not benefit from either phase arrangement, depending on the left-turning and the opposing traffic demand.

For some experimental traffic arrangements lagging phases produce significantly less delay to all traffic on an approach. But when all experimental traffic demand cases were tested together, the difference was not significant. Approach delay under actuated control is dependent on the interactive performance of all vehicles using an approach and the relative efficiency and relative magnitude of each vehicular maneuver.

Dual leading left-turn phasing was compared with dual lagging for the same 20 traffic demand combinations that were examined in the corresponding pretimed experiment with four additional special cases. Because dual lag phasing generally produced shorter cycle lengths and less delay than dual lead phasing, a supplementary experiment was designed in an attempt to produce shorter cycle durations with dual lead phasing. The left-turn lane loop detectors were incrementally shortened in three tests, and a shorter vehicle extension interval was used for left-turn traffic.

Although forcing the left-turn traffic to use the permissive portion of the green signal by causing early gap-out of the protected left-turn phase causes the cycle duration to be reduced, it was never as short as with dual lag phasing. Vehicular delay was consistently less for dual lagging sequencing schemes. The dual lagging sequence was, therefore, judged to be more efficient than dual leading.

Dual Versus Split Phasing

As noted earlier, split phase timing patterns were developed for 20 traffic demand situations. Vehicular delay for through and left-turn movements was compared with the corresponding statistics gathered under dual left-turn sequencing. Results of the comparisons were virtually identical to those produced under pretimed control. Therefore, the conditions determining whether split or dual phasing should be used do not change when actuated instead of pretimed control is used.

Leading Versus Lagging Split Phasing

In cases where split left-turn sequences are selected under actuated control, the question of which left-turn movement should lead a through movement green may arise. To determine whether the leading left-turn movement performs differently than the lagging movement in a split left-turn phase arrangement, 20 traffic approach demand combinations were compared for each of the two situations.

The results indicate that there is no significant difference in delay to left-turning or to through vehicles when a lagging phase is used instead of a leading phase, even though the required phase lengths are very different. This is because the left-turn queue discharges more efficiently with a leading phase minimizing delay to individual vehicles, but it requires a longer phase to do so, causing a longer cycle duration and more delay at the intersection. On the other hand, because the lagging phase is shorter, the main street green signal must be longer to process the through vehicles that would be processed with the left-turn vehicles with a leading phase. Thus, there is no significant difference between leading and lagging phases with split left turns and actuated control.

FINDINGS AND RECOMMENDATIONS

The preceding discussion has included a comparative examination of left-turn phase sequence patterns. Random variability of generated traffic data has been considered an important aspect of the study and has been treated through multiple replication of experimental units. Comparative analyses have been developed around traffic operational data with vehicular delay as the primary measure of effectiveness. Safety-related issues have been included through a review of published safety data (2-6). Based on these analyses the following findings have been developed.

1. From a traffic operations perspective, provision of permissive left turns during the through green will always be beneficial regardless of the type of signal control or left-turn sequence pattern. Published data (2-6) indicate that safety problems associated with permissive lefts are frequently not severe. Intersection approach speeds greater than 45 mph are frequently cited as a reason for prohibiting permissive left turns.

2. There is no operational difference between dual leading and dual lagging sequences when permissive left turns are prohibited. When permissive turning is allowed, dual leading sequences produce less vehicular delay than dual lagging sequences if pretimed signal control is used. Under actuated control, dual lagging sequence patterns tend to produce less vehicular delay.

3. The choice of dual versus split phase sequence patterns is not generally affected by the type of signal controller. Split phasing will be the more efficient sequence pattern where the critical left-turn and through movement traffic demands occur on the same approach and left-turn processing time for one approach is greater than the through movement processing time.

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