Possible PASSER II Enhancements

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The PASSER II computer program for optimization of arterial signal timing has been accepted by usage. It has been used extensively during the last few years. The program's ability to select multiphase sequences for a maximum bandwidth progression solution has led to its increasing use and application. The PASSER II maximum bandwidth solution has been well accepted and implemented throughout this country. The theory, model structure, methodology, and logic in the PASSER II computer program has been evaluated and documented. An evaluation was undertaken to determine if several enhancements to the PASSER II program as related to a revised green split procedure, a minimum delay cycle length, and number of alternate optimal solutions could improve the utility of the solution and would be useful measures. The comparison was to the existing PASSER II computer program and comparison TRANSYT program runs. This evaluation showed, for the three scenarios considered, that a revision for the green split routine provided equal saturation splits. An advisory minimum delay cycle length calculation would provide useful guidance in the selection of the cycle length range to consider. Other measures, like a minimum delay performance measure, alternate optimal solutions, and improved delay measure, could provide useful results.

The PASSER II computer program for optimization of signal timing on arterials has been accepted by usage and is being used extensively. The program's ability to select multiphase sequences for a maximum bandwidth progression solution has led to its increasing use in the last few years. The PASSER II maximum bandwidth solution has been well accepted and implemented throughout this country. The theory, model structure, methodology, and logic in the PASSER II computer program have been evaluated and documented.

The PASSER II computer model was developed by Messer and others (1) and modified to an off-line computer program by Messer (2). It was developed primarily for high-type arterial streets (i.e., those that have intersections with protected left-turn lanes and phases) (3). It is applicable for the timing for modern eight-phase controllers.

The PASSER II computer program can be classified as a macroscopic deterministic optimization model. It uses a platoon level representation for fixed (uniform) traffic volumes and speeds. The optimization procedure is an implicit enumeration of the minimum interference values and uses a variant of the half-integer synchronization approach for relative offsets. The unique advantage the PASSER II program has over other optimization programs for signalization is that it can be used to consider and select multiple phase sequences (4).

The optimal bandwidth solution is selected as the lowest minimum interference sum. Two measures are used to determine the worthiness of the solution--efficiency and attainability.

CYCLE LENGTH

An investigation was conducted to determine whether the cycle length selected by the PASSER II program corresponded to the minimum cycle length (over the range studied) for the traffic network study tool (TRANSYT) program (5). This investigation was part of a larger study to develop a heuristic programming approach to arterial signal timing (6).

A four-signal arterial street was selected for the evaluation. It was considered large enough to permit signal and link characteristics not to especially affect the traffic behavior and results of the study.

It was decided to evaluate three cycle lengths to evaluate the minimum delay and progression solution interaction. The three cycle lengths selected were 80, 90, and 100 s, which appeared to be representative values and still provided a nominal range and three solution points.

To permit some range of spacing, three intersection spacings were considered to study the effect of the interrelation between cycle length and intersection spacings--full scale, half scale, and quarter scale. The morning peak-period volume condition was used for the evaluation.

The arterial street selected, Skillman Avenue, was not considered ideal for either progression or minimum delay objectives. Figure 1 shows the four intersections used. In general, all intersections are high-type and all signalization is multiple phase with protected turning. Figure 2 shows the full-scale intersection spacing.

Table 1 lists the three intersection spacings considered.

COMPARISON OF CYCLE LENGTH SOLUTIONS

For three spacing scenarios (full scale, half scale, and quarter scale), runs were made for the three cycle lengths (80, 90, and 100 s). The efficiency of the PASSER II optimal solutions for the three intersection spacings and cycle lengths are provided in the table below

	Efficiency by Cycle Length		
Scenario	80s	90s	100s
Full scale	0.341	0.299	0.398
Half scale	0.382	0.393	0.346
Quarter scale	0.349	0.328	0.310

For the full-scale scenario, the optimal cycle length is 100 s. For the half-scale scenario, the optimal cycle length is 90 s. An 80-s cycle length is the optimal solution for the quarter-scale scenario. The efficiency of the solution obtained varies as the cycle length changes for each of the three scenarios. The shape of the efficiency curve for the cycle lengths for each of the scenarios is shown in Figure 3. For the full-scale scenario, the efficiency curve is nonmonotonic and illustrates the effect of cycle length on the progression efficiency of the arterial street.

Number of Alternate Optimal Solutions

For the phasing combination for the optimal solution, the PASSER II program outputs the last phasing sequence that was considered. Although alternate optimal phasing arrangements may exist to the phasing sequence selected, the program has no means to identify these. Different phasing arrangements may satisfy the progression criteria. From a progression standpoint, there is no advantage of these alternative solutions over the one selected.

Although which of the alternate optimal phasing arrangement that PASSER II selected does not affect the progression solutions, the phasing arrangement may have an important effect on the minimum delay solution. Also one of the alternate optimal phasing arrangements may allow the traffic engineer to pick the type of phasing he or she would like to use for other than progression considerations (i.e., safety and consistency). A physical change in the phasing arrangement can be a major undertaking in the field; therefore, these alternate optimal phasing arrangements can be important.

For each of the cycle lengths, the alternate optimal phasing arrangements were determined by explicit enumeration. The number of optimal phasing sequences for each cycle length and spacing scenario is listed in Table 2.

The phasing alternatives were numerically described for each intersection as

1. Left-turns first,
2. Through movements first,
3. Leading green, and
4. Lagging green.

As an example of the phasing description of the four-signal arterial overall, a phasing combination of 1342 would be intersection one left-turns first (1), intersection two leading green (3), intersection three lagging green (4), and intersection four through movements first (2). Each phasing arrangement will be indicated by using a dash as the delimiter mark. The example would be shown as 1-3-4-2.

For the full-scale scenario, there was only 1 optimal phasing sequence for the 80-s cycle length. There were 17 alternative optimal sequences for 90 s, and 21 alternative optimal phasing sequences for 100-s cycle length.

For the half-scale scenario, there were 9 alternative optimal phasing arrangements for the 80-s cycle length. There were 4 alternative optimal sequences for 90 s, and 12 alternative optimal phasing arrangements for the 100-s cycle length.

The quarter-scale scenario had only one optimal phasing sequence for the 80-s cycle length. There were three optimal phasing arrangements for 90 s. Four phasing arrangements were optimal for the 100-s cycle length.

Overall, for each of the scenarios, there were few alternative optimal phasing arrangements for the 80-s cycle length. There were several alternative optimal phasing arrangements for the 90-s cycle length. For the 100-s cycle length there were more

Figure 1. Location of Skillman Avenue, Dallas.

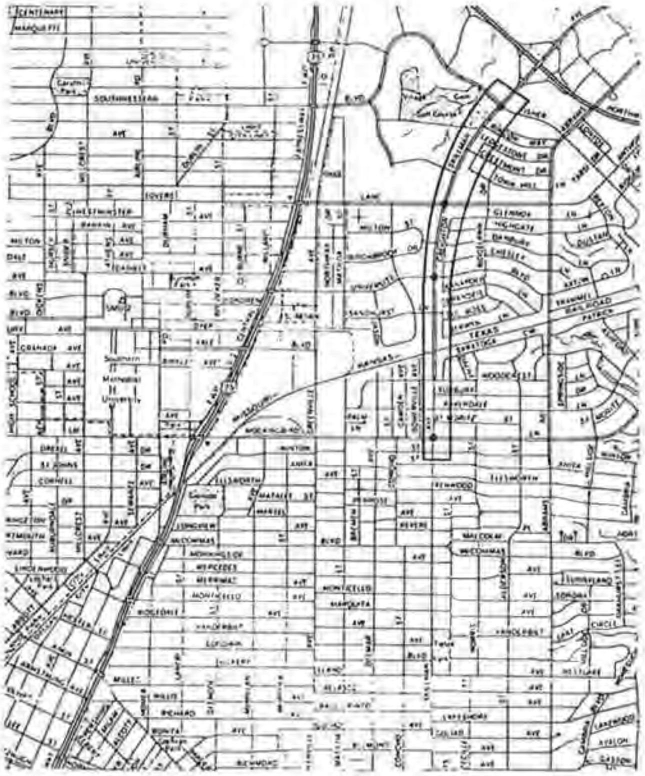


Figure 2. Skillman Avenue line drawing with spacing.

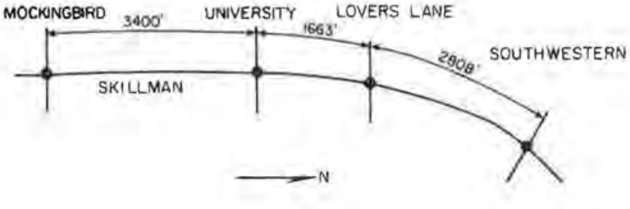


Table 1. Intersection spacing scenarios.

Link	Link Spacing (ft) Full Scale	Half Scale	Quarter Scale
South of Mockingbird	3000	3000	3000
Mockingbird to University	3400	1700	850
University to Lovers Lane	1663	832	416
Lovers Lane to Southwestern	2808	1404	702
North of Southwestern	3000	3000	3000
Cross street approaches	2000	2000	2000
Entry links	1000	1000	1000

Figure 3. PASSER II efficiency versus cycle length for scenarios.

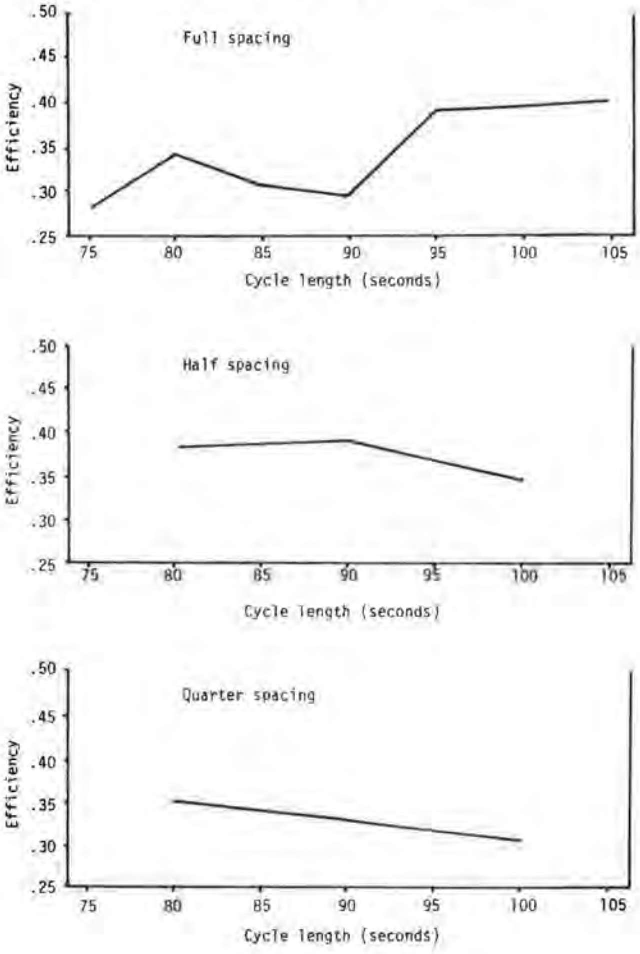


Table 2. Number of PASSER II alternate optimal solutions for three intersection spacing and cycle lengths.

	PASSER II Alternate Optimal Solutions by Cycle Length		
Scenario	80 s	90 s	100 s
Full scale	3-4-4-3[a]	3-1-1-4	2-1-1-4
		3-1-2-4	2-1-2-4
		3-1-3-4	2-1-3-4
		3-1-4-4	2-2-1-4
		3-2-1-4	2-2-2-4
		3-2-2-4	2-2-3-4
		3-2-3-4	2-4-1-4
		3-2-4-4	2-4-2-4
		3-3-1-4	2-4-3-4
		3-3-2-4	3-1-3-1
		3-3-3-4	3-1-3-2
		3-3-4-4	3-1-3-4
		3-4-1-4	3-2-3-1
		3-4-2-4[a]	3-2-3-2
		3-4-3-4	3-2-3-4
		3-4-4-4	3-3-3-1
			3-3-3-2
			3-3-3-4
			3-4-3-1
			3-4-3-2
			3-4-3-4[a]
Half scale	2-1-4-1	4-1-4-3	4-1-1-3
	2-1-4-2	4-2-4-3	4-1-2-3
	2-2-4-1	4-3-4-3	4-1-4-3
	2-2-4-2	4-4-4-3[a]	4-2-1-3
	2-3-4-1		4-2-2-3
	2-3-4-2[a]		4-2-4-3
	3-3-1-3		4-3-1-3
	3-3-2-3		4-3-2-3
	3-3-4-3		4-3-4-3[a]
			4-4-1-3
			4-4-2-3
			4-4-4-3
Quarter scale	4-3-3-4[a]	4-3-3-1	4-3-3-1
		4-3-3-2	4-3-3-2
		4-3-3-4[a]	4-3-3-3
			4-3-3-4[a]

[a] PASSER II selected optimal solution.

alternative optimal phasing arrangements.

The number of alternate optimal phasing sequences would appear to increase with larger cycle lengths. The effect of intersection spacing would be an additional factor. This arises from the greater flexibility permitted by the larger green times and space periodicity. These increases allow different phasing arrangements at the noncritical intersections without affecting the efficiency of the optimal solution.

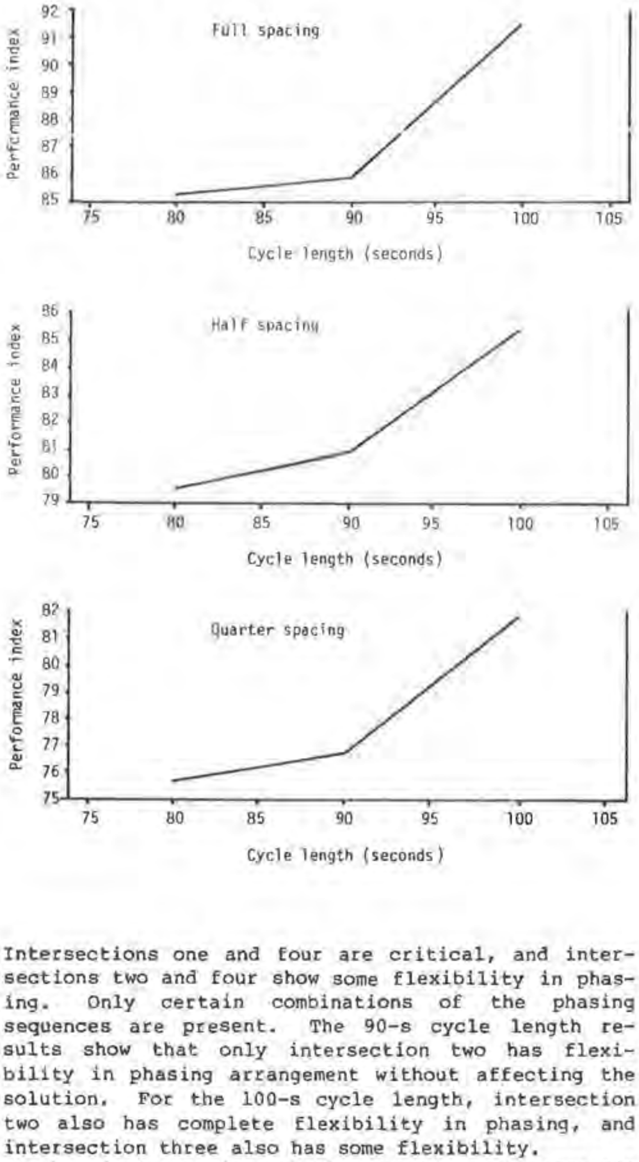
For the full-scale scenario, there is no flexibility at the 80-s cycle length and no alternate optimal solutions. The 90-s cycle length has some flexibility. At this cycle length, the first and last intersections are critical and the phasing arrangement is for intersection one leading green and intersection four lagging green. For the two inside intersections (two and three) that are noncritical, any phasing combination is possible because of the flexibility. Flexibility is even greater with the 100-s cycle length. There appears to be two sets of critical intersections for this cycle length. Either intersections one and four with phasing of through movements first (2) and lagging green (4), respectively, or intersections one and three with phasing of leading green (3) are critical. There is not complete flexibility of the phasing of the noncritical intersections, however, since not all four arrangements were present.

The intermediate spacing of the half-scale scenario shows slightly different results. There are alternate optimal phasing arrangements for the 80-s cycle length, as can be observed from Table 2. Intersections one and four are critical, and intersections two and four show some flexibility in phasing. Only certain combinations of the phasing sequences are present. The 90-s cycle length results show that only intersection two has flexibility in phasing arrangement without affecting the solution. For the 100-s cycle length, intersection two also has complete flexibility in phasing, and intersection three also has some flexibility.

The short spacing of the quarter-scale scenario again shows limited ability of alternate optimal phasing. The only flexibility in phasing is for intersection four for the larger cycle length.

The combination of longer green time, spacing periodicity, and flexibility in phasing arrangement alternatives for a given optimal solution is apparent. For each cycle length and intersection spacing combination, the intersections that are noncritical cause the alternative optimal phasing arrangements for the progression optimal solution.

Figure 4. Plot of performance index versus cycle length for scenarios.



TRANSYT Runs

Corresponding runs were made for the scenarios by using the TRANSYT6B program. For the three spacing scenarios, the lowest TRANSYT performance index was for the 80-s cycle lengths. The relation between TRANSYT performance index and cycle length is illustrated in Figure 4. These data would indicate that the average delay would increase monotonically as the cycle length is increased from 80 s (for the cycle length range considered).

Comparison of PASSER II and TRANSYT

The comparison of cycle lengths for TRANSYT and PASSER II results would indicate, for this study, that the PASSER II optimal cycle length is not usually the minimum delay solution cycle length from TRANSYT. This comparison shows that, potentially, a minimum delay cycle length would need to be incorporated as part of the PASSER II program to alleviate this problem.

The determination of a minimum delay cycle length used the previous runs to provide a calculation to find the minimum delay cycle length. The evaluation was whether the cycle length calculation permitted the selection of the minimum delay cycle length for each scenario.

Green Split Routine

The procedure used in the PASSER II program for traffic signal timing for splits is to distribute the available effective green time in proportion to the critical movement volume to saturation capacity flow rate ratios. The methodology is derived from Webster's concept and uses the critical lane analysis approach (7).

The routine has a limitation in common with many others--the initial green split between the arterial street and the minor street at each intersection is made on the ratio to the critical lane volume sum. The street time is then allocated (split) between the opposing movements in the ratio of the relative critical lane volumes. A check is then made whether each movement time exceeds its minimum green time. When the movement green time is less than the minimum green time, the remainder of the time needed is taken off the paired opposing movement time and the times are adjusted.

In the case where the times are adjusted, the minimum green times are satisfied, but the saturation ratio and opposing movement green time has been changed. For the critical intersection or a critical movement, the adjustment can result in poor operation from increased saturation on the opposing link. The method results in the split between the arterial street and the cross street remaining the same.

In certain situations, with the model arterial being one, this taking from the opposing movement can cause poor performance measures. The STAR1 routine in TRANSYT follows a slightly different approach by using equal saturation. From the TRANSYT runs comparison, the existing PASSER II green split routine outperforms the STAR1 routine for one scenario. A revised PASSER II green split routine was developed by using a modified equal saturation basis.

The revised routine developed retains the existing green split routine through determining which movements do not have their minimum green times satisfied. This deficit time for each movement green is used to calculate an equivalent vehicular volume. This volume is added to the original volume. The green times are recalculated by using the critical lane analysis. These revised green times are checked against the respective green times for each movement. Although the possibility exists for one to four deficit times per intersection, in actuality only two of the movement deficits determine the split allocation.

If after the first recalculation the minimum green time still remains unsatisfied, the resultant deficits are redetermined, the equivalent volumes computed, and the critical lane analysis and green splits are recalculated. After this second recalculation, the resulting green times were considered to be close to the minimum green times (for the critical movements). The incremental improvement for additional recalculations would be small.

At this point, the proposed procedure would revert to the existing procedure. The test for satisfying the minimum green is done. The original deficit movements are adjusted to their minimum green times. This is done for a threefold purpose. First, there may still exist original deficit (critical) movements that have not been increased to the minimum green times (that must be satisfied). The second reason is that the noncritical deficit movements could have been overcompensated and exceed their minimum green times (and should be adjusted back to their minimum times). The third reason is that the revised green splits may have caused a satisfied initial movement time (i.e., no initial deficit) to end up slightly deficit. At this step, the original deficit movements and any currently deficit movements are set to their minimum green times and a corresponding adjustment is made to their paired opposing movement time.

The effect of this revised green split routine is to cause (if two) the two critical deficit movements for an intersection to have equal saturation ratios. The other movements saturation ratio (and green time) are affected from this adjustment to the original split. However, the effect may be added or reduced green time, depending on their relation to the deficit movements.

A comparison between the original green split times and the revised green split times for each intersection showed differences (Table 3). This arose because of the heavy through movement and light left-turn volumes (opposing). The result was that the arterial had several deficit movements. This result is hidden in the present program output unless a visual comparison is made to the minimum green time and the paired opposing movement. The revised procedure green split times for the 90-s and the 100-s cycle lengths are compared with the original green splits in Tables 4 and 5.

The mixed performance for the PASSER II splits versus the STAR1 splits is not surprising. In the original routine the deficits are compensated from the opposing movements, which usually are at a critical level of saturation. As the cycle length is increased (from 80 s), the number of deficit movements and movement time is reduced. This could explain why the original PASSER II green split routine gave mixed results for the different cycle lengths. The revised procedure does not modify the original green splits unless there is a deficit movement. It would appear that the poorer performance of the PASSER II green split results (at the lower cycle lengths) would improve with the revised procedure. At the higher cycle lengths, where the PASSER II results were sometimes better than those of STAR1, it would appear that the revised procedure would only slightly alter the original green splits.

To evaluate the revised green split routine, the calculations were manually performed and input into the existing PASSER II program as minimum green times to force the desired splits. The phasing combinations that are optimal for the three scenarios were determined. The original alternate optimal PASSER II phasing combinations and the best TRANSYT phasing sequence for each scenario were rerun.

In most cases the revised results provided a slightly lower efficiency and bandwidth, since more green time was provided to an intersectional cross movement. The recalculation of the green splits yielded more green time for the cross street and less for the main street. The results are provided in Table 6 and Figure 5.

The effect of the revised green split routine on a progression solution depends on which movements are deficit. For example, if both a cross street movement and a through movement are (equally) deficit, the green split between the cross street and the main street would not change. The allocation of green time for the cross street movements and the main street movements individually will be changed.

Minimum Delay Cycle Length

Although progression has been widely accepted for arterial signals, Webster (8) originally recognized that the consideration of delay minimization was necessary in the selection of the cycle length to be used for each intersection. Webster's cycle calculation, however, is only applicable to two-phase signal operation.

A direct estimate of the minimum delay cycle length that is appropriate for the highly saturated conditions would be desirable. A possible approach is to use the flow ratios directly with the lost time to estimate the minimum delay cycle length. By using a modified critical movement analysis approach, the y_is for each intersection would be determined. The opposing movement y_is would be

Table 3. Comparison of PASSER II green splits from original and revised procedure for 80-s cycle.

Street	Movement	Original (SPLIT1)	Revised (SPLIT2)	Street	Movement	Original (SPLIT1)	Revised (SPLIT2)
Mockingbird	1[a]	10.0	10.0	University	1	10.0	10.0
	2	32.2	30.9		2	51.4	51.8
	3	13.1	12.7		3	10.0	10.0
	4	29.1	28.2		4	51.4	51.8
	5	20.9	21.6		6	18.6	18.2
	6	16.9	17.5		8	18.6	18.2
	7[a]	10.0	10.0				
	8	27.8	29.1				
Lovers Lane	1[a]	10.0	10.0	Southwestern	1[a]	10.0	10.0
	2	39.0	39.0		2	36.3	37.0
	3[a]	10.0	10.0		3[a]	10.0	10.0
	4	39.0	39.0		4	36.3	37.0
	5	10.0	10.0		5	12.7	12.0
	6[a]	21.0	21.0		6[a]	21.0	21.0
	7	10.0	10.0		7[a]	10.0	10.0
	8	21.0	21.0		8	23.7	23.0

[a] Deficit minimum green movements.

Table 4. Comparison of PASSER II green splits from original and revised procedure for 90-s cycle.

Street	Movement	Original (SPLIT1)	Revised (SPLIT2)	Street	Movement	Original (SPLIT1)	Revised (SPLIT2)
Mockingbird	1[a]	10.0	10.0	University	1	10.0	10.0
	2	37.6	36.0		2	59.2	59.5
	3	14.5	14.0		3	10.0	10.0
	4	33.1	32.0		4	59.2	59.5
	5	23.5	24.4		6	20.8	20.5
	6	18.9	19.6		8	20.8	20.5
	7[a]	10.0	10.0				
	8	32.4	34.0				
Lovers Lane	1[a]	10.0	10.0	Southwestern	1[a]	10.0	10.0
	2	46.7	47.2		2	42.3	43.7
	3	10.5	10.9		3[a]	10.0	10.0
	4	46.2	46.3		4	42.3	43.7
	5	12.3	11.8		5	14.8	14.3
	6[a]	21.0	21.0		6	22.9	22.0
	7	10.5	10.5		7[a]	10.0	10.0
	8	22.8	22.3		8	27.7	26.3

[a] Deficit minimum green movements.

Table 5. Comparison of PASSER II green splits from original and revised procedure for 100-s cycle.

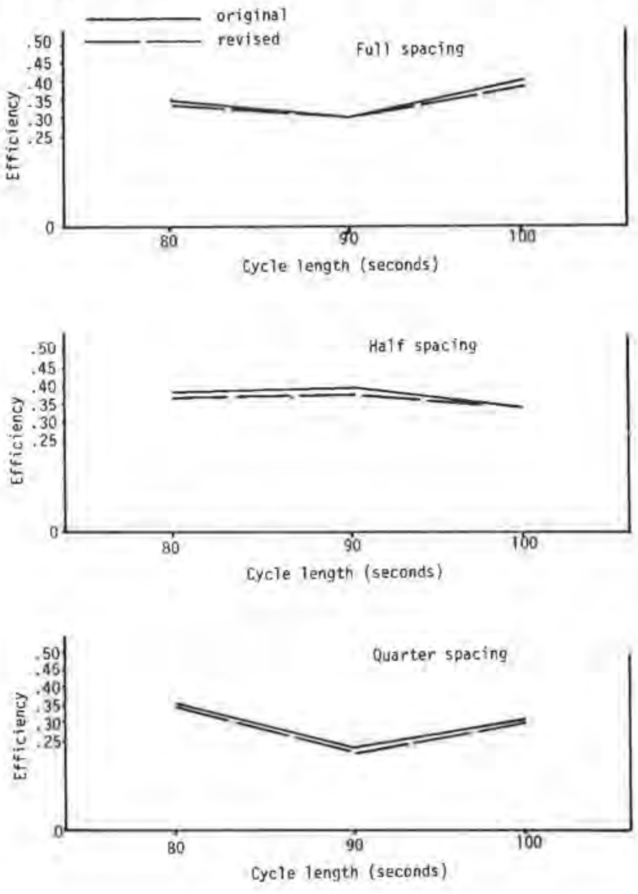
Street	Movement	Original (SPLIT1)	Revised (SPLIT2)	Street	Movement	Original (SPLIT1)	Revised (SPLIT2)
Mockingbird	1[a]	10.1	10.0	University	1	10.0	10.0
	2	42.8	41.1		2	67.0	67.2
	3	15.9	15.4		3	10.0	10.0
	4	37.0	35.7		4	67.0	67.2
	5	26.1	27.1		6	23.0	22.8
	6	21.0	21.7		8	23.0	22.8
	7[a]	10.0	10.0				
	8	37.1	39.0				
Lovers Lane	1[a]	10.0	10.0	Southwestern	1[a]	10.0	10.0
	2	53.3	53.5		2	48.3	49.5
	3	11.4	11.5		3[a]	10.0	10.0
	4	51.9	51.8		4	48.3	50.0
	5	15.7	15.5		5	16.3	15.7
	6[a]	21.0	21.0		6	25.4	24.5
	7	11.3	11.4		7[a]	10.0	10.0
	8	25.4	25.1		8	31.7	30.2

[a] Deficit minimum green movements.

Table 6. Comparison of PASSER II selected solutions for original and revised split procedures.

Scenario	Cycle Length (s)	Original		Revised	
		Phasing Sequence	Efficiency	Phasing Sequence	Efficiency
Full scale	80	3443	0.341	3443	0.335
	90	3424	0.299	3424	0.298
	100	3434	0.398	1434	0.384
Half scale	80	2342	0.382	1341	0.369
	90	4443	0.393	4343	0.377
	100	4343	0.346	4343	0.345
Quarter scale	80	4334	0.349	4334	0.343
	90	4334	0.328	4334	0.321
	100	4334	0.310	4333	0.302

Figure 5. Plot of efficiency versus cycle length for scenarios from original and revised procedures.



summed. A determination would be made of which pair was the greater for each street. These maximum paired y_is would be summed for the intersection and the following equation used to estimate the appropriate cycle length, i.e.,

$$\Sigma(Y_i/X_i)\,C + nl \leq C \tag{1}$$

i.e., critical, or

$$C \leq nl/[1 - \Sigma(Y_i/X_i)] \tag{2}$$

where

C = cycle length,
nl = lost time,
Y_i = flow ratio (g/s), and
X_i = desired x-ratio.

This procedure does not evaluate for deficit green times, therefore, an adjustment for low y_is was proposed to compensate for this shortcoming. The adjustment for the critical movement y_is is if one of the opposing pair y_is is less than 0.10 and the other movement is greater than 0.25, then the low y_i (less than 0.10) is multiplied by 1.1. This provides for a compensation for those movement y_is that are critical and likely would be deficit. The steps in the procedure are as follows:

Step 1: Calculate y_is,
Step 2: Adjust the y_is if necessary, and
Step 3: Calculate C from the equation.

By using the model arterial intersection data and a x-ratio of 0.85, the following minimum delay cycle lengths were determined: Mockingbird, 91 s; University, 39 s; Lovers Lane, 73 s; and Southwestern, 87 s.

If a cycle length was selected within the range of 0.75 and 1.25 of the minimum delay cycle length, the delay might only be increased slightly; i.e.,

$$0.75\,C_{min} \leq C \leq 1.25\,C_{min} \tag{3}$$

By using this recommended range the proposed procedure calculates the minimum cycle lengths for each intersection shown in the table below. In actuality the low cycle length determined may be less than the sum of minimum greens. Since the minimum greens are the absolute lowest cycle length possible, a check must be made for the range of cycles determined.

	Cycle Length (s)	
Intersection	Low	High
Mockingbird	68	113
University	29	49
Lovers Lane	54	90
Southwestern	65	108

For the four intersections, the sum of minimum greens is 57, 41, 62, and 60 s, respectively. The low cycles for University and Lovers Lane both violate this limit and would need to be changed to the limit. Because of the three-phase signal at University Drive, its cycle length range is much lower than that of the other (four-phase) signals. Its cycle length range also falls below the remaining signals sum of minimum green. Because of this, the cycle length range that would be selected must fall outside of University Drive's minimum delay cycle length. From the cycle length range of the remaining three signals, it would appear that a range of 68-90 s could be selected.

SUMMARY

The proposed enhancements appear to have the capability to alleviate certain of the differences between the PASSER II solutions and the TRANSYT solutions. A minimum delay cycle length range procedure is needed to consider the effect of delay in a progression solution. The need for a revised green split routine in the PASSER II program was apparent in the differences between the STAR1 and TRANSYT solutions and the PASSER II split solutions.

The procedures developed provide only estimates for the minimum delay cycle length and equal saturation green splits. More rigorous and complete procedures could be developed to provide a better estimate.

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Evaluation of Signal Timing Variables by Using A Signal Timing Optimization Program

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This paper presents the results of a limited study to evaluate the effects of signal timing variables on the selection of the signal timing plan and the resulting measures of effectiveness from a signal timing optimization program. The TRANSYT computer program was used for the evaluation. Several series of sensitivity tests were performed to study the interrelations among number of signalized intersections, signal spacing, cycle length, and traffic flow conditions. The evaluation showed varying effects of the signal timing variables on the results. There appeared to be consistency in results for different signal system configurations (number of signals). With fixed signal spacing and number of signals, the measure of effectiveness (performance index) increased with volume level and cycle length. The effect of signal spacing illustrated differences in the behavior of the performance index. These results show the trade-offs between signal spacing and cycle length for a fixed number of signals and traffic volume level. As the cycle length was increased, the performance index also increased (although sometimes only slightly). This may suggest the use of the shortest practical cycle length for a progressive operation.

With ever-increasing loads being placed on urban traffic facilities from growing traffic demands, the retention of urban mobility depends to a very large extent on the effective use of urban street signal systems. The signalized intersections of urban arterials are a critical element of the urban street system. Traffic congestion and other operational deficiencies are common along arterial streets. Excessive or unnecessary delays, stops, and fuel consumption are experienced due to the inefficient operation of the signalization system. The safe and efficient movement of arterial traffic is almost totally a function of the signal timing variables. By virtue of their operation, traffic signals cause delay to motorists (1). The intersection characteristics usually determine the efficiency and capacity of the entire street system (2). The need exists to develop improved traffic control technology for facilitating the optimal use of available capacity (3).

Improvement of the effectiveness of the traffic control parameters would contribute to reducing the congestion and to relieving those conditions that impede the flow of traffic. The selection of a signal timing plan is complicated by the large number of alternatives available and the interrelations among the signal timing parameters (4). A considerable amount of research has been done on coordination of traffic signals on urban arterial streets (5). Efforts have been directed toward computerized signal timing optimization programs that would provide for signal timing plans superior to those in use.

The maximum bandwidth progression solution has been the approach preferred by traffic engineers (6-8). This arises in part from the lack of computational complexity in use and the ability to visualize the goodness of the results. Although progression has been widely accepted and used, concerns have arisen as to whether it provides a good arterial solution at the expense of the cross street traffic. Other methods for setting arterial traffic signals are the minimum delay solution and the combination of minimum delay with fuel consumption. Even with the theoretical development and computational efficiency of progression and minimum delay techniques, the final criteria is that both techniques have been accepted as providing a good solution (9).

Settings for fixed-time coordinated traffic signals are based on safety of traffic, capacity of the intersection, and delay minimization (10). Signal timing plans must take into account not only the