System Partition Technique to Improve Signal Coordination and Traffic Progression

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System Partition Technique to Improve Signal Coordination and Traffic Progression

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Abstract: A heuristic approach to the application of bandwidth-oriented signal timing is proposed based on a system partition technique. The proposed approach divides a large signalized arterial into subsystems with three to five signals in each subsystem. Each subsystem is optimized to achieve the maximum bandwidth efficiency. A one-directional system progression bandwidth, normally in the peak-flow direction, is then formed by appropriately adjusting the offsets between each subsystem. Such an approach provides a signal-timing solution that would achieve maximum progression for the peak direction while still maintaining partial progression for the off-peak direction. Further improvements on signal timing may be achieved by adjusting the phasing sequences at the subsystem boundary locations. A case study is presented to illustrate how the proposed approach can be applied, and the timing solutions are compared with the solutions from traditional signal-timing software. Evaluation of the timing solutions using CORSIM simulation indicates that the proposed approach results in improved bandwidth efficiencies for both directions and improved performance measures such as stops and travel speeds. The proposed heuristic approach is easy to apply using existing signal timing software packages such as PASSER II and Synchro. The proposed approach could also be used to develop new or improved existing bandwidth optimization algorithms.

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Introduction

Progression bandwidth or bandwidth efficiency is one of the major criterions for judging the quality of a coordinated signal timing plan. However, when the number of signals in a system increases (e.g., more than 10 signals), it becomes more difficult to obtain a good bandwidth solution. In fact, attempting to use a small progression band for an entire arterial system may not be a good practice in signal timing and coordination. For example, traffic entering an arterial may not go through the entire system to fully utilize a system progression band. On the other hand, vehicles are likely to drop out of the progression band if the bandwidth is narrow and the travel speed deviates from the desired progression speed.

Speed variation is commonly due to variations in drivers' behavior, vehicle characteristics, and traffic flow conditions, most notably queuing and congestion, which can significantly reduce vehicles' travel speeds. Traffic engineers and researchers have recognized the necessity of dividing a large system into smaller subsystems, a technique called *system partition* (Husch and Albeck 2003). The purpose of this study is to propose a signal-timing approach based on a system partition technique. A case study is presented to demonstrate the applications of the proposed approach, and comparisons are made with the timing solutions by traditional signal optimization methodologies.

Several signal-timing software packages are available that can provide optimized signal-timing solutions. However, each software package has its unique optimization features based on different optimization objectives. There are basically two types of signal timing software in a broad category: bandwidth based and delay based. Examples of bandwidth-based software packages include PASSER II (1990) [see also Chang et al. (1988)], MAXBAND (Little et al. 1981), and MULTI-BAND (Gartner 1991; Sripathi et al. 1995). Examples of delay based software packages include TRANSYT 7-F (2001) and Synchro (Husch and Albeck 2003). Bandwidth-based software focuses on maximizing the bandwidth as the primary objective in deriving an optimized signal-timing solution. Such a timing solution works better if the arterial through traffic is the predominant movement. Delay-based software focuses on minimizing system delays as the primary objective in deriving an optimized signal-timing solution. Bandwidth is usually a by-product of the optimization process.

Efforts have been made in the past to combine the advantages of both bandwidth-based and delay-based solutions. For example, TRANSYT-7F (Wallace and Courage 1982) has incorporated a PROS (progression opportunity) measure in its optimization routine. The PROS represents a partial progression band, which aims at further reducing stops and delays for those vehicles traveling outside the progression band. MULTI-BAND remedies the major shortcomings of pure bandwidth-based solutions by taking into account the actual traffic flow patterns. The software still focuses on maximizing the bandwidth, but the bandwidth could be a partial band within a portion of a system depending on the actual traffic flows.

Despite the various shortcomings of bandwidth-based signal timing, bandwidth is still viewed with high regard in the traffic engineering community in judging the quality of a timing plan,

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because it is the most visible indicator to individual drivers. A signal timing solution, no matter how well it may minimize system delays and stops, may not be acceptable to traffic engineers and jurisdictions if the timing solution does not have a good progression band. A study conducted by Yang (2001) has indicated that bandwidth-based solutions generally outperform delay-based solutions based on several field studies.

As pointed out earlier, one of the problems of developing bandwidth-based signal timing is that the bandwidth tends to decrease with the increase of number of signals in a system. At a certain point, obtaining a system bandwidth may become impossible. This is the nature of bandwidth and progression, which has nothing to do with which software is used. In practice, when a system exceeds a certain number of signals and obtaining an optimized bandwidth becomes difficult, a viable approach is to divide the network into subsystems (a system partition process) before optimization. System partition, although an important issue in signal timing, has not been addressed in most traffic optimization software packages.

Synchro is perhaps the only software that has a feature of system partition application. With the system partition feature, the software calculates an empirical *coordinatability factor* based on several variables such as distance, travel time, and traffic volume. The *coordinatability factor* provides indications whether an intersection should be coordinated with other signals in the system. For example, a *coordinatability factor* of 100 means the signal should be coordinated with other signals, while a *factor* below 20 would suggests that the signal operates better independently. Our proposed approach is somewhat different from that used in Synchro. Said approach would still maintain coordination among all the signals, but the objective is to maximize the system's progression band for one direction, and at the same time allow the other direction having good partial progression band among partitioned subsystems. A large system is first divided into subsystems. Optimization is performed for each subsystem, and a final timing plan is created from the subsystem's timings.

The remainder of the paper is organized as follows. First, the paper provides some background of the bandwidth optimization methodologies. The proposed system partition technique is then outlined, and a case study is presented to illustrate the proposed technique. The timing solutions from both PASSER II optimization and the proposed approach are evaluated using CORSIM (TSIS 2003) microscopic simulation model. Finally, a summary and conclusions are provided.

Bandwidth Optimization Algorithms

The bandwidth optimization algorithm developed by Brook and Little establishes the primary principles of bandwidth optimization. The algorithm was originally developed for two-phase signals. Most bandwidth-based software packages adopted these principles. For example, Messer et al. (1973) enhanced the original algorithm to handle multiphase signals. The basic principles of the algorithm are presented next to illustrate why the bandwidth decreases with the increase of number of signals.

Fig. 1 illustrates the basic concepts of Brook's bandwidth optimization algorithm using three signals with simple two-phase operations. In an arterial such as shown in Fig. 1, the intersection with the minimum arterial green split, $G_{\min}$, is called the critical intersection (e.g., the middle intersection in Fig. 1). The arterial green times for the other intersections in the system are all greater

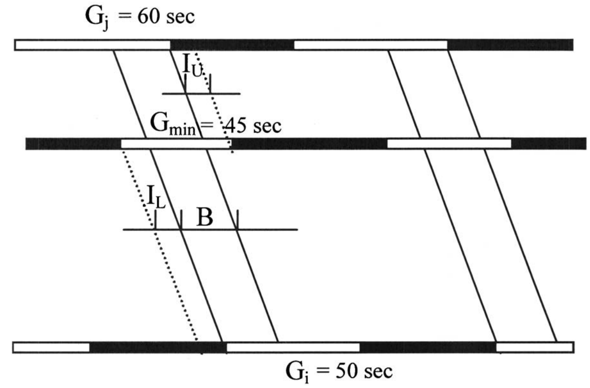


Fig. 1. Illustration of bandwidth optimization concepts

than $G_{\min}$. This minimum green time, $G_{\min}$, determines the largest possible bandwidth that can be achieved for the system. The system bandwidth is reduced if the progression band encounters *interference* from other signals in the system. Only one type of interference, either an upper interference, I_U, or a lower interference, I_L, can occur at each signal. The final system bandwidth, B, is determined by $G_{\min}$ minus the minimum possible combination of the upper interference and the lower interference, as shown in Eq. (1)

$$B = G_{\min} - \min\{\max_{\forall i}(I_{U,i}) + \max_{\forall j}(I_{L,j})\} \tag{1}$$

where B=bandwidth (s); $I_{U,i}$=upper interference at intersection i (s); $I_{L,j}$=lower interference at intersection j (s); $\max_{\forall i}(I_i^U)$=maximum value from all signals producing upper interference (s); and $\max_{\forall j}(I_j^L)$=maximum value from all signals producing lower interference (s).

The enhanced Brook's algorithms such as those in PASSER II and MAXBAND search for the best phasing sequences and offsets at each signal location to minimize the combined interference. The optimization process simultaneously considers progression in both directions. If desired, a one-way progression bandwidth can always be achieved at its maximum possible ($G_{\min}$) with appropriate offset adjustments at each signal.

To maximize the progression bandwidths for both directions, the offset and phasing of each signal should be carefully designed. For an intersection j with multiphases (e.g., the option of a leading left turn phase or a lagging left turn phase), the interference for one direction is also related to the timing parameters for the other direction. Eqs. (2) and (3) show how the upper interference or the lower interference can be calculated for intersection j with respect to a master intersection m for one of the directions (e.g., direction a)

$$I_{U,j}(p) = [G_{\min} - T_{mj} + T_{jm} - O_m(n) + O_j(p) + G_j] \bmod C \tag{2}$$

$$I_{L,j}(p) = [T_{mj} + T_{jm} - O_m(n) + O_j(p) - S_j] \bmod C \tag{3}$$

where $I_{U,i}(p)$, $I_{L,j}(p)$=upper interference and lower interference at intersection j with phase sequence p (only one phase sequence could occur) (s); T_{mj}, T_{jm}=travel times between intersections m and j (s); $O_m(n)$=relative offset between direction a green time and direction b green time at signal m with phase sequence n (s); $O_j(p)$=relative offset between direction a green time and direction b green time at signal j with phase sequence p (s); G_j=direction a green time at signal j (s); S_j=difference between green times of intersections j and m in direction b (s); and C=cycle length (s).

Eqs. (1)–(3) suggest that the interference (either upper or lower) is largely affected by the signal spacing as reflected by the travel times, T_{mj} and T_{jm}. With the increase of the number of signals in a system, the chances of having larger interference values increase. For example, there might be a signal whose spacing may actually produce maximum interference, which equals to $G_{\min}$, the green time of the reference intersection. In this case, the bandwidth would be zero.

Attainability, A_B as described in Eq. (4), is a useful measure to indicate how close a bandwidth is to its maximum possible. When attainability is at 100%, the bandwidth is at its maximum.

$$A_B = \frac{B}{G_{\min}} \times 100\% \tag{4}$$

Note that the bandwidth optimization algorithm used in PASSER II can provide a guaranteed maximum bandwidth solution for two-phase signals. However, when signals have multiphases, a maximum bandwidth solution is not guaranteed, especially when the number of signals is large.

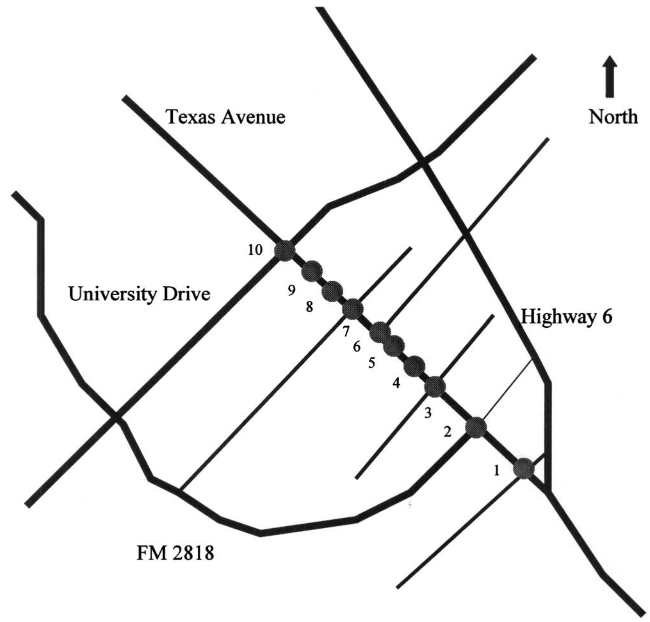


Fig. 2. Signal system map: Texas Avenue

Proposed Signal Timing Approach

The proposed signal timing approach seeks a bandwidth-based solution, that is, to achieve the maximum possible progression band for the system. However, unlike the traditional optimization routines, our approach is to seek a maximum bandwidth for one direction and the best partial bandwidth for the other direction. Therefore, it overcomes the problems with the existing bandwidth-based solutions in systems with a large number of signals. Our definition of partial bandwidth is also somewhat different from the traditional partial bandwidth concept. Our partial bandwidth refers to a bandwidth within a subsystem, while the traditional partial bandwidth can exist within any portion of an entire system. The proposed approach is outlined in the following steps:

1. Divide the system into subsystems with each subsystem having three to five signals. Having three to five signals in a subsystem is purely heuristic, but it can usually achieve the maximum bandwidth for the subsystem (e.g., with a 100% attainability). The actual number of signals in a subsystem may vary as long as near 100% attainability values can be achieved. Software packages such as PASSER II and MAXBAND can be used to obtain the optimized bandwidth solutions for each subsystem. The process could eventually be automated using attainability as the selection criteria.
2. Combine the timings from the optimized subsystem solutions to form an initial timing solution. Primarily, the subsystem's progression bands are combined to form a system progression band for one direction, typically the peak-traffic direction. The resulting peak-direction bandwidth is determined by the smallest bandwidth of all the subsystems. A system progression band for the off-peak direction is not guaranteed after combining the subsystems, but the subsystem bandwidth or partial bandwidth will still remain because the relationship among all the signals within a subsystem does not change.
3. Fine-tune the initial timing solution from Step 2 to further improve progression for the off-peak direction. Improvement can be achieved if a better connection can be established between the subsystem's partial progression bands. This can be accomplished by making some phasing adjustments while joining the progression bands from two neighboring subsystems. For example, a progression band connection can be improved by using a lead/lag phasing or by switching the lead/lag sequence at the subsystem's boundary signals. It is likely that the subsystem bandwidth will be affected after such phasing changes, but the impact on the bandwidth is expected to be minor since each subsystem has only three to five signals.

Case Study

Site Description

A case study is presented in this section to illustrate the proposed signal timing approach. The test site is *Texas Avenue* in College Station, Tex. Fig. 2 is a map of the system. Texas Avenue is a major north/south arterial serving traffic generated by the major business centers of City of College Station and Texas A&M University. The posted speed limit on Texas Avenue ranges between 35 mph (56 km/h) and 45 mph (73 km/h). For demonstration purposes and easy plotting of the time-space diagrams, a speed of 40 mph (64 km/h) was used to develop the timing plans. The signal system has 10 signals, and Table 1 summarizes the major traffic control characteristics of each intersection.

The traffic volumes used for developing timing are derived based on the weekday a.m. peak hour. The system has an approximate 70/30 directional flow split, with the northbound being the peak direction during the a.m. peak period. Split phasing is used for the cross streets at several signal locations, serving major left-turn traffic volumes coming from or going to the cross streets. Examples of such locations are George Bush Dr. and FM 2818. At George Bush Dr., a major northbound left-turn movement serves traffic going to the Texas A&M University campus. At FM 2818, an eastbound left-turn movement serves a major traffic flow to the

Table 1. Summary of Traffic and Control Characteristics

Intersection number	Cross street name	Spacing (m)	Main street left-turn phasing	Cross street left-turn phasing
1	Deacon Dr.	—	Prot./perm.[a]	Split
2	FM 2818	1,056	Prot./perm.	Split
3	SW Parkway	1,006	Prot./perm.	Prot./perm.
4	Brentwood Rd.	282	Prot./perm.	Prot./perm.
5	Holleman Dr.	610	Prot.	Split
6[b]	Harvey Rd.	377	Prot.	T-intersection
7	George Bush Dr.	575	Prot.	Split
8	Walton Rd.	797	Prot.	Prot./perm.
9	Lone Star Dr.	396	Prot./perm.	T-intersection
10	University Dr.	305	Prot.	Prot.

[a]Prot.=protected; Perm.=permitted.

[b]Southbound through (Phase 2) at Intersection 6 is uncontrolled.

business centers as well as the Texas A&M campus. The existing system is operating at a 120-s cycle during the a.m. peak period.

PASSER II Optimization Solution

Although several bandwidth-based software packages can be used in the study, we select PASSER II as the primary analysis tool because of its popularity and availability. To ensure a fair comparison, the existing cycle length and the green splits at each intersection are kept unchanged for both the PASSER II optimization and our proposed signal timing approach. To be consistent with the directional flow split, a 70/30 split is selected to perform the bandwidth optimization in PASSER II. Fig. 3 is the resulting time-space diagram from PASSER II. The system bandwidths for both directions are plotted in Fig. 3.

As shown in Fig. 3, the PASSER II solution produces a northbound bandwidth of 15 s with an attainability of 45%, and a southbound bandwidth of 5 s with an attainability of 16%. Such low attainability values are typical when a system involves 10 or more signals. The dotted lines are presentations of some traditional partial bandwidths, indicating traffic being able to progress through part of the system. The resulting offsets of all the signals, referred to the start of green of the main-street through phases, are also shown in the figure. The PASSER II timing solution indicates that good partial progression bands do exis, even though the system bandwidths are small. The timing solution is considered a decent solution, but the majority of the arterial traffic would expect to stop within the system due to the small system bandwidths.

Proposed Timing Approach and Solution

The proposed signal timing approach and the resulting timing plans are illustrated in Figs. 4–6. The first step is to divide the entire system into smaller subsystems. Division of the subsystem is usually based on consideration of the spacing between intersections, as well as such traffic flow characteristics as volume and queue conditions. For example, each subsystem should contain 3 to 5 signals. Another consideration is that the subsystem boundary should be selected where the intersection has high volume-to-capacity (v/c) ratios, high turning traffic volumes, and long spacing between intersections. Selecting subsystem boundaries at such locations has the advantages of avoiding queue spillback and regrouping vehicles to start at the next progression band. For example, intersections with high v/c ratios normally have long queues. Progressed traffic is likely to be affected by the queues and thus may fall outside of the progression band. However, these vehicles can be regrouped and start progressing through the remaining signals in the next green band. Such a strategy is most effective while dealing with oversaturated or congested arterials.

In our study case, the entire system is divided into three subsystems. As a general observation, the intersections at George Bush Dr. and Holleman Dr. are critical intersections with split phasing on the cross streets and high turning traffic volumes coming from and going to the cross streets. There is also relatively large spacing at these locations. Once the subsystems are formed, PASSER II was used to develop an optimized bandwidth solution for each subsystem. Fig. 4 illustrates the resulting time-space diagrams for the three subsystems, where the absolute maximum bandwidths are all achieved as indicated by the 100% attainability for all the subsystems (intersections marked with ** in the figure have the minimum green times equal to the bandwidths).

The next step is to form a system progression band for the peak (northbound) direction. The bandwidth of the peak direction is controlled by the smallest bandwidth of all the subsystems. In our case, the smallest northbound bandwidth was 38 s, which is given by the second subsystem (Holleman Dr.–George Bush Dr.). Forming the peak direction band can be obtained by either using computer software or through numerical calculations. Synchro has a graphical interface that allows the users to move the offsets and view changes to the time-space diagram. Numerical calculations can be performed to calculate the beginning progression band at each subsystem boundaries, and the required offsets to be adjusted at each signal to form the system band. An example of numerical calculations is illustrated below.

If a master controller exists at a signal location (i.e., all offsets are referenced to that intersection), the offsets of all the signals within the same subsystem need not be changed; only the offsets of signals in the other subsystems need to be adjusted. In our case, the master controller is located at the University Dr. intersection (Subsystem 1). Therefore, offset adjustments need to be made for the signals in Subsystems 2 and 3. As indicated in Fig. 4(a), the beginning band at University Dr., t_m, is at 88 s, which is obtained by subtracting the phase 1 time (northbound LT of $\phi_1 = 32$ s) from the offset O_m at University Dr. Subtracting the travel time between Walton Rd. and University Dr. (calculated at 39 s), the beginning band of Subsystem 1 at Walton Rd., t_0^1, is calculated at $88-39=49$ s. Subtracting further the travel time between George Bush Dr. and Walton Rd. (calculated at 44 s), the beginning band for Subsystem 2 at George Bush Dr., t_e^2 is $49-44=5$ s, $120+5=125$ s.

At present, the offset at George Bush Dr., O_2, is 105 s, and the beginning band ($t_e'^2$) at George Bush Dr. at current offset is obtained at 86 s by subtracting the phase 1 time of 19 s from the current offset ($105-19=86$ s). To create a northbound progression band, the beginnings of the subsystem bands need to be aligned, which would require increasing the offset George Bush Dr. by $125-86=39$ s. All the signals within Subsystem 2 should be added with the same offset value of 39 s, which results in a new set of offsets for all the signals in Subsystem 2.

For example, the new set of offsets would be 24 ($105+39=144=24$) s for George Bush Dr., 77 ($38+39=77$) s for Harvey Rd., and 71 ($32+39=71$) s for Holleman Dr., respectively. Similarly, the offsets in Subsystem 3 also need to be adjusted to create a northbound system progression band. Fig. 5 is the resulting time-space diagram after the above adjustments. As

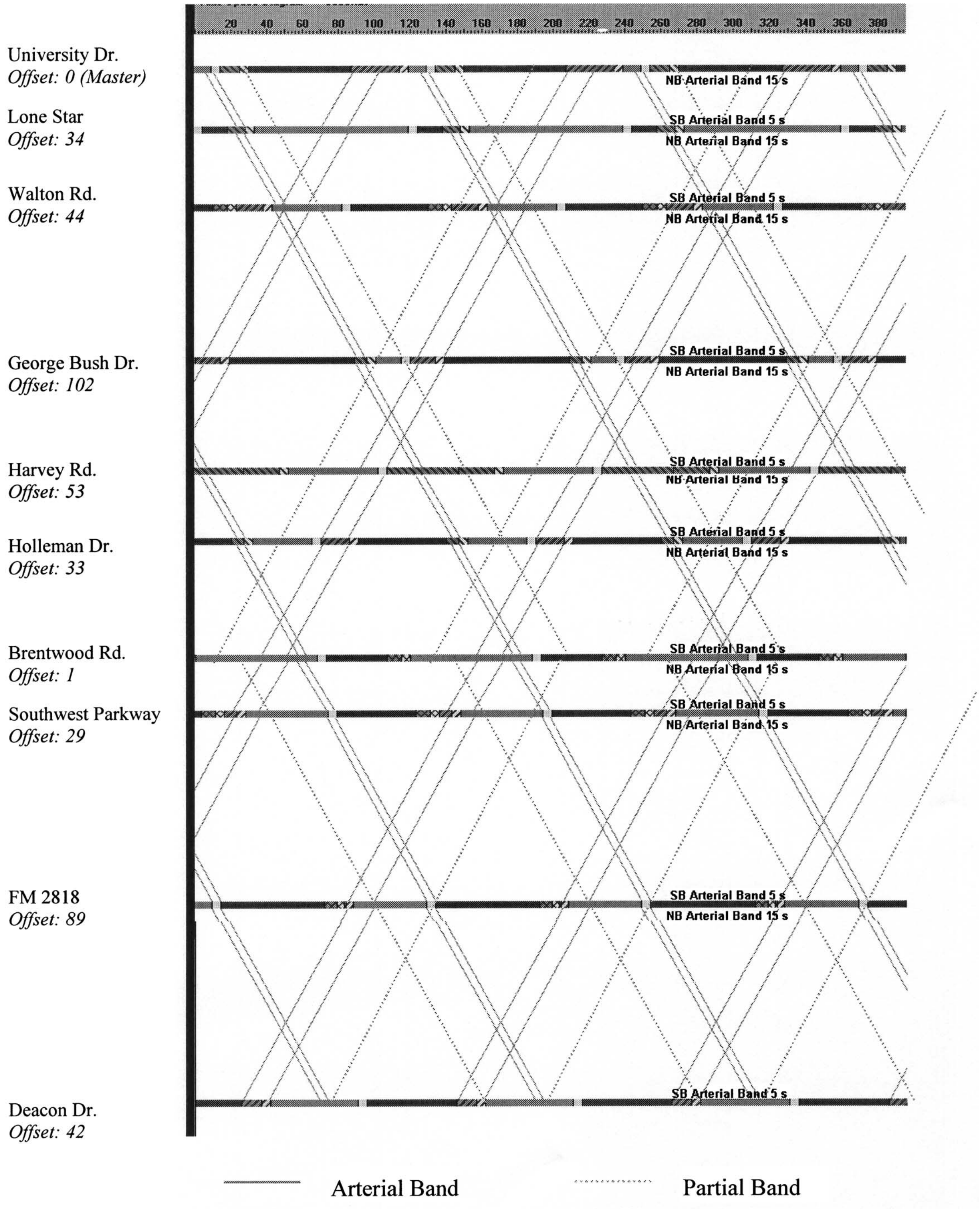
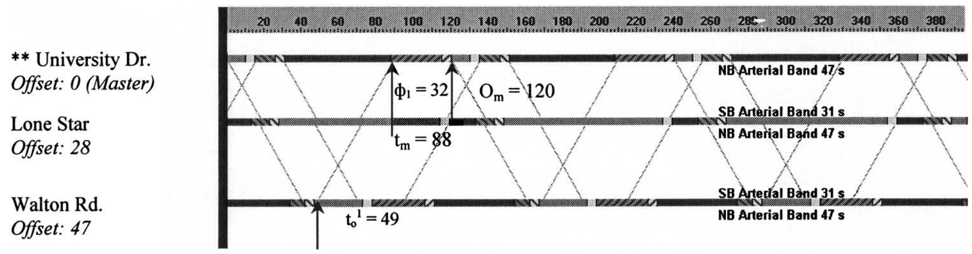


Fig. 3. Time-space diagram from PASSER II solution

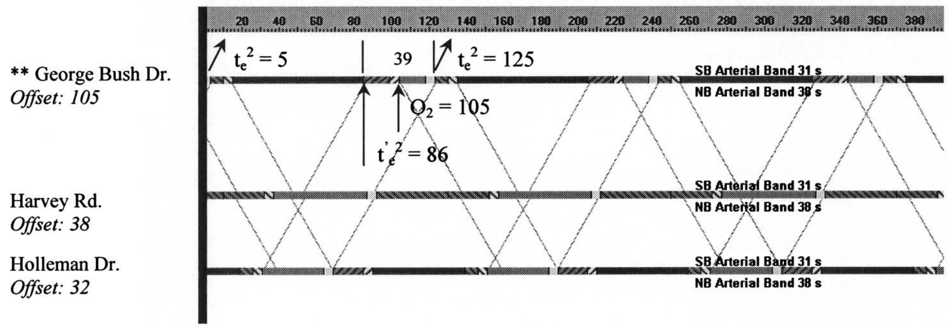
can be seen, the peak direction bandwidth is maximized at 38 s. The off-peak direction does not have a system bandwidth, but the partial subsystem's bandwidths are retained. Such a timing solution has the advantages of providing maximum progression for the peak direction while still giving progression considerations in the off-peak direction. The traffic in the off-peak direction can at least progress through each subsystem without stop.

Although a similar peak direction bandwidth can be obtained directly from PASSER II by selecting an appropriate optimization strategy (e.g., selecting a 99/1 split option), there will be no control on the off-peak direction's partial bands. Our proposed signal timing approach would give the traffic engineer complete control over where the partial progression band is desired and the expected stopping and queue storage locations. Although the off-peak direction may not have a system bandwidth, vehicles can at least travel through each subsystem without having to stop, giving drivers a better perception by limiting the chances of making consecutive stops. In addition, due to the large partial bandwidth within each subsystem, the link performances within each subsystem can generally be improved.

The signal timing solution created so far may still be improved by further examining possible phasing changes at the subsystem boundary intersections. As stated earlier, the main objective of the adjustments is to improve band connections for the off-peak di-



(a) Time-Space Diagram for Sub-System 1



(b) Time-Space Diagram for Sub-System 2

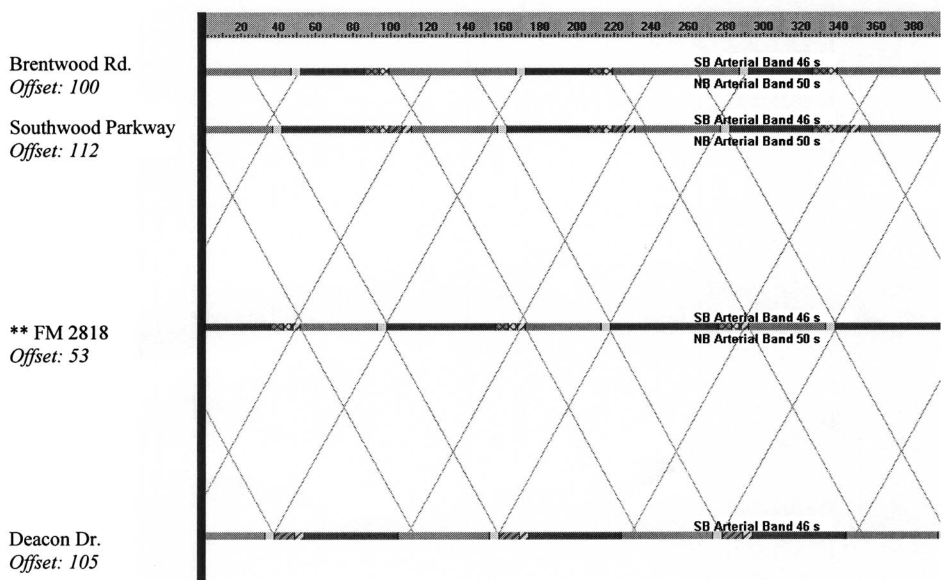


Fig. 4. Optimized time-space diagrams for subsystems

rection by either using a lead/lag phasing or changing the lead/lag phasing sequences. Although some jurisdictions may have concerns regarding the use of lead/lag phasing or change of phasing sequences, it is generally found that using lead/lag phasing can significantly improve the timing efficiency, especially for bandwidth-oriented solutions. Driver's expectancy is usually not a major issue (Buckholz 1993). Since the number of signals within a subsystem is small, the impact of a phasing change on a subsystem's bandwidth is typically insignificant.

Using the Texas Avenue system as an example, when a change is made on the lead/lag phasing sequence at the Walton Rd. intersection (i.e., to change to northbound left-turn leading and southbound left-turn lagging from the existing phasing sequence), the off-peak progression bands of Subsystems 1 and 2 are better connected. If the change is made, it would require reoptimization of the timing for each subsystem. Similarly, a phasing sequence change at Holleman Dr. intersection would also improve the band connection for Subsystems 2 and 3. Fig. 6 shows the final timing plan after these phasing changes are made. As shown, a 10-s progression band is created for the off-peak direction while the peak direction progression band of 38 s is retained. Compared to the original PASSER II solution with the bandwidths of 15 and 5 s for the two directions, our proposed approach results in significant improvement in bandwidth efficiency and attainability.

A general qualitative evaluation can be made for the two timing plans generated from PASSER II and the proposed approach. Our proposed approach achieves the maximum progression band for the peak direction, and also results in a better system band for the off-peak direction. In addition, our proposed approach also results in improved partial band progressions, as explained using

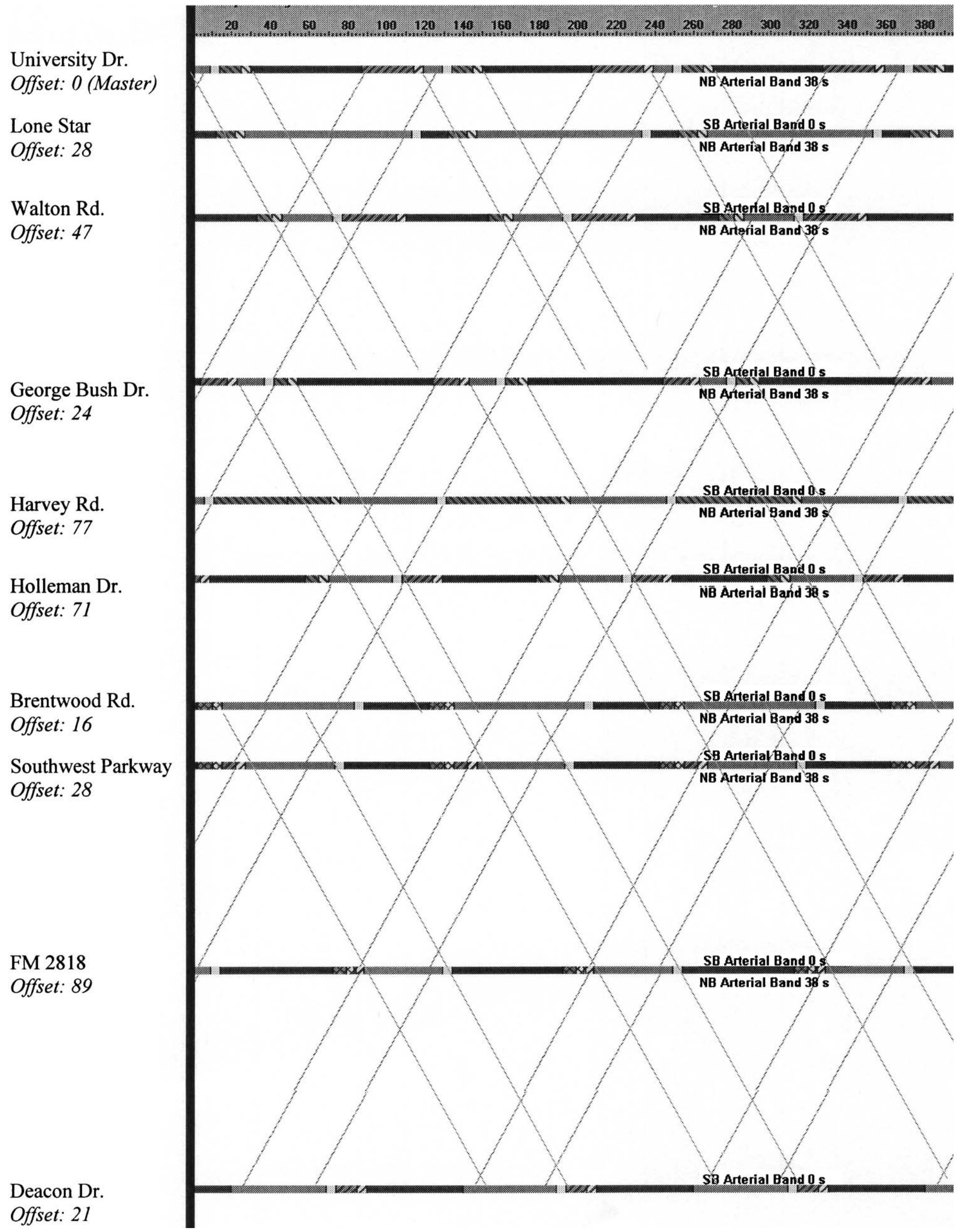


Fig. 5. Combined time-space diagram from subsystems

the following example. The original solution from PASSER II shown in Fig. 3 indicates some good partial bands.

However, notice that for each direction, the first partial band lags the system band, and the second partial band leads the system band. Such a partial band relationship would result in longer delays for those vehicles stopped at the end of the first partial band, since they would have to wait for the next green band to progress further through the system. As for the timing from our proposed approach shown in Fig. 6, the partial band for the off-peak direction can enable the traffic to better progress, since the first partial band leads the system band and the second partial band lags the system band. Any vehicles stopped at the end of the first partial band would experience a minimum delay and would further progress through the second partial band. Note that the cases illustrated here may be particular to this study.

The proposed signal-timing approach has been illustrated primarily as a heuristic approach, but it shows that an improved bandwidth solution can be achieved compared to the PASSER II optimization result. The findings from this study provide valuable information for possible future enhancements to the bandwidth optimization algorithms. The proposed signal-timing approach is especially effective when the signal system has a large number of signals, say, more than 10 signals. With a signal system with a large number of signals, PASSER II or other optimization software would be less likely to produce a good bandwidth solution when applied to the entire system. As illustrated in the case study, bandwidth optimization algorithms may be approached by partitioning the system first and then seeking optimized solutions for the subsystems and then for the entire system. A good rule of thumb of system partition is to have three to five signals in a subsystem or as long as high attainabilities, as defined by Eq. (4), can be achieved for the subsystem. The subsystem boundaries also need to be selected where critical intersections are located as well as large spacing exists between the adjacent intersections.

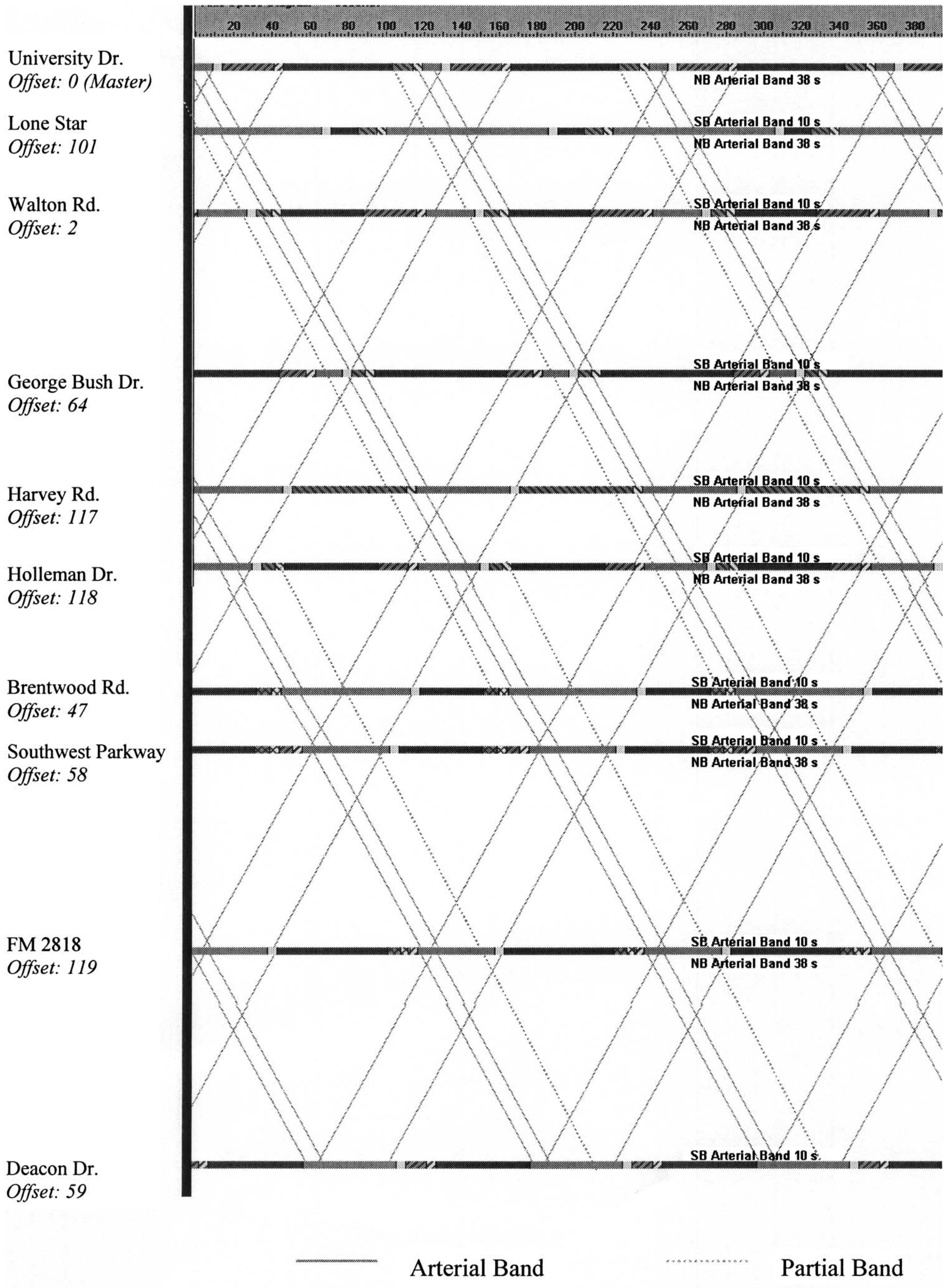


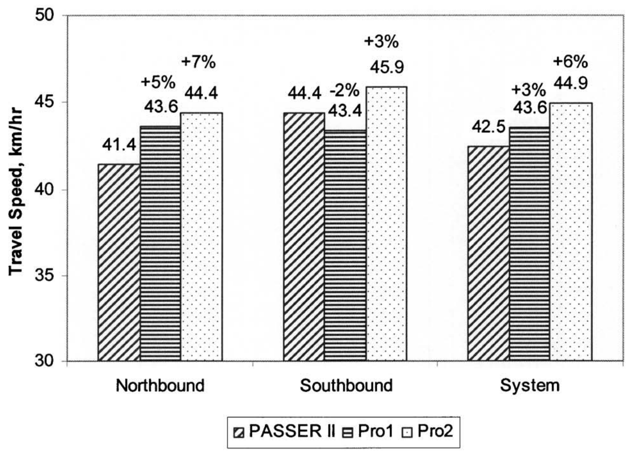
Fig. 6. Final time-space diagram with adjustments

Simulation Evaluation

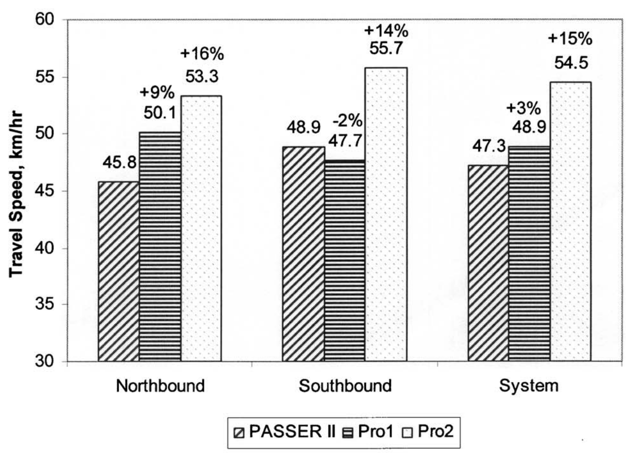
More detailed evaluations on the timing solutions presented previously are conducted using the CORSIM microscopic simulation model. Before presenting the simulation results, it is important to mention a relevant signal timing strategy when involving split phasing on the cross street. For the study system, there are several locations where split phasing is used for the cross streets. The use of split phasing in the study system is mainly to serve the heavy left-turn traffic volumes from the cross street. Although the cross-street phasing does not affect the system progression band, appropriate design of the split-phasing sequence can improve the operations for the left-turn traffic.

For simulation evaluation purposes, adjustments on the cross-street split-phasing sequence were made for all the timing solutions evaluated. The strategy is to select the split-phasing sequence so that the left-turn traffic coming from the cross street could better progress. For example, at FM2818 intersection, the eastbound to northbound left-turn traffic is a major movement. A preferred phasing sequence is to lead the westbound phase and lag the eastbound phase, so that the eastbound left-turn traffic could be better accommodated by the northbound progression band, which immediately follows the left-turn traffic.

Three timing solutions are evaluated in simulation, which include the one from the original PASSER II optimization (Fig. 3), the one with the initial proposed approach (Fig. 5), and the one with the final adjustments (Fig. 6). All the simulation results are based on the average of 10 multiple runs with a different random seed for each run.



(a) Average Speeds of All Vehicles



(b) Average Speeds of Arterial Through Vehicles

Fig. 7. Comparison of average speeds

Fig. 7 shows the speed results in each direction for the three timing solutions. Fig. 7(a) shows the average speeds for all the vehicles, while Fig. 7(b) shows the speeds for the arterial through traffic only. As shown in Fig. 7(a), the two timing plans from the proposed approach yield higher travel speed for the northbound direction. However, the initial timing solution (noted as Pro1) results in lower travel speed for the southbound direction. Nevertheless, the average travel speed for both directions shows improvement over the initial PASSER II solution. The initial proposed timing solution results in a speed increase of about 3%, and the timing with the final adjustments (shown as Pro2) results in an increase of about 6%.

Travel speeds for the arterial through vehicles shown in Fig. 7(b) are estimated from simulation by coding some bus-type vehicles (e.g., vehicles coded as bus but with similar driving characteristics as passenger cars). Only buses in CORSIM can have designated routes traveling through the entire system. About 50 such bus-type vehicles per hour are coded in simulation for each direction, with each vehicle entering the system randomly. The average speed of such bus-type vehicles is used to estimate the travel speed for the through vehicles. As shown in Fig. 7(b), the proposed timing solutions generally indicate more significant improvements for the through traffic. With the initial proposed timing (noted as Pro1), the average speed for both directions increases by about 3%, but the improvement is about 15% with the final proposed timing solution (noted as Pro2). The results indicate that the proposed timing solutions can result in significant benefit to the arterial through traffic. The proposed bandwidth-oriented signal timing approach may have resulted in increased delays to the non-through traffic movements in this case. When arterial through traffic is significant, our proposed approach would produce more efficient signal timing solutions.

Summary and Conclusions

Unlike the traditional bandwidth-based signal-timing methodologies, a signal timing approach based on system partition technique was proposed in this study. The timing approach would allow maximum progression for the peak direction by providing the maximum possible progression band, while still providing partial progression for the off-peak direction by providing progression bands in each subsystem. The partial band would allow traffic progressing through a subsystem without stop. At the same time, the location to progress and stop traffic can be easily seen and controlled. The two timing approaches were evaluated using microscopic simulation model. The following is a summary of the major findings and conclusions:

- The proposed timing approach was shown to be a viable solution when dealing with large systems. For the study case presented, the proposed approach resulted in significant increase in bandwidth efficiency and attainability for both directions. The proposed approach resulted in bandwidths of 38 and 10 s for the two directions, compared to 15 and 5 s from PASSER II when optimizing the entire system.
- Evaluations of the timing solutions using microscopic simulation showed that the timing plans from the proposed approach resulted in improved system operations, especially for the arterial through traffic. With the proposed timing solution, the average travel speed for all the vehicles increased by about 6%, and the average speed for arterial through traffic increased by about 15%.
- Although the proposed approach is primarily heuristic, it can be easily applied by traffic engineers with bandwidth optimization software such as PASSER II and some user-friendly time-space diagram generation software such as Synchro. A rule of thumb of dividing subsystems is to have three to five signals where near 100% attainability can be achieved. Defining subsystems should also consider other factors such as v/c ratio and link distance. Subsystem boundaries should be at intersections that have high v/c ratios and where the distance to the adjacent subsystem is long.

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