

A SYSTEM PARTITION APPROACH TO IMPROVE SIGNAL TIMING

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Abstract

A new approach to application of bandwidth-oriented signal timing is proposed based on a system partition technique. The proposed approach is to divide a large arterial signal system into subsystems with 3 to 5 signals in each subsystem. Each subsystem is optimized to achieve the maximum bandwidth efficiency. A one-directional system progression bandwidth, normally the peak-flow direction is then formed by appropriately adjusting the offsets between each subsystem. Such a signal timing solution would provide maximum progression for the peak direction while still maintaining partial progression for the off-peak direction, where vehicles can at least go through each subsystem without having to stop. 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 was applied, and the timing solutions were compared with the solution from PASSER II software. The results showed increased bandwidth efficiencies for both directions and improved performance measures on stops and travel speeds. Although the proposed approach was illustrated primarily as being heuristic, it is generally easy to apply with the features of signal timing software packages such as PASSER II and Synchro. The general concept of the proposed approach could also be adopted to develop new or to improve existing bandwidth optimization algorithms such as the one used in PASSER II.

Key Words: Signal Timing, System Partition, Progression, PASSER II, Synchro

Introduction

Traffic progression bandwidth or bandwidth efficiency is one of the major parameters for evaluation on traffic progression in coordinated signal systems. However, when a signal system has a large number signals (e.g., more than 10 signals), it is often difficult to achieve a good system bandwidth by using general signal-timing software packages, such as PASSER II (1), TRANSYT 7-F(2) and Synchro (3). In fact, attempting to achieve a total system progression band having low bandwidth efficiency may not be an efficient approach to developing signal-timing plans. For example, traffic entering an arterial may not go through the entire system to take full advantage of a system progression band. On the other hand, vehicles are very likely to drop out of the progression band if the bandwidth is narrow and the travel speed varies from the desired progression speed. Speed variation is common due to different driving behaviors and normal traffic flow characteristics such as queuing and congestion. Traffic engineers and researchers previously recognized the necessity of dividing a large system into smaller sub-systems, using a technique called *system partition*. The purpose of this paper is to propose a signal timing approach related to system partition. A case study is presented to demonstrate the applications of the proposed approach, and to compare the timing solutions with the one from PASSER II optimization software.

Synchro is the only signal timing software package to address system partition issues. The software provides the user with an opportunity to determine whether a signal should be coordinated with the adjacent signals based on an empirically calculated *coordinatability factor*, such that an entire system may be divided into sub-systems. The calculation of the coordinatability factor uses parameters such as distance, travel time and traffic volume, and the recommendation is based on the fact that each sub-system will operate independently, i.e., there is no coordination (not common cycle length) among each sub-system. Our proposed approach is

somewhat different from that used in Synchro. Instead, our system partition approach still focuses on maintaining coordination of all the signals, but to seek alternative signal-timing solutions other than those directly produced from the signal-timing software packages. Primarily, the proposed approach seeks a maximum bandwidth-oriented solution within subsystems rather than the total system, although an improved system bandwidth, as will be demonstrated in this paper may be achieved using the proposed approach. A large system is first divided into sub-systems. Optimization is performed for each sub-system, and a final timing plan is created from the sub-system's timings. The first section of the paper provides some background of the bandwidth optimization technique used by PASSER II. The proposed signal timing approach is then outlined. A case study is presented to illustrate the process of the proposed approach. The timing solutions from both PASSER II optimization and the proposed approach are evaluated using CORSIM (4) microscopic simulation model. Finally, summary and conclusions are provided.

Bandwidth Optimization Algorithm

Among various signal-timing software packages, PASSER II is probably the only software package that can optimize phasing, cycle, splits and offsets to achieve a maximum bandwidth-oriented signal timing solution (5). Although other signal timing software packages may also perform optimization on the above signal timing parameters, they are typically designed to minimize system stops and delays (2,3). Nevertheless, bandwidth is still perceived with high regard in the traffic engineering community in judging the quality of a timing plan, since it is the most visible indicator to traffic engineers and jurisdictions. A signal timing solution, no matter how well it can minimize system delay and stops, may still not be acceptable by traffic engineers and jurisdictions if the timing solution does not have a good progression band.

The bandwidth optimization algorithm in PASSER II was originally developed by Brook (6) for two-phase signals, and later revised by Messer et. al. (7) to optimize multi-phase signals. The algorithm seeks the maximum bandwidth for a signal system by optimizing the general signal timing parameters. While maximizing the bandwidth is always the primary objective of the PASSER II optimization algorithm, the algorithm is also equipped with offset fine-tuning routines to minimize delay and stops, which would produce some partial progression band, similar to the PROS (Progression Opportunities) optimization technique in TRANSYT 7-F.

Figure 1 illustrates the basic concepts using three signals with simple two-phase operations for the bandwidth optimization algorithm adopted in PASSER II. In an arterial such as shown in Figure 1, the intersection with the minimum arterial green split G_{min} , is called the critical intersection (e.g., the middle intersection in Figure 1). The arterial green times for the other intersections in the system are all greater 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 upper interference (e.g., I_U) or lower interference (e.g., 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 Equation 1.

$$B = G_{min} - \min\{ \max_{\forall i} (I_i^U) + \max_{\forall j} (I_j^L) \} \quad (1)$$

where

B = final bandwidth

I_i^U = upper interference at intersection I

I_j^L = lower interference at intersection j

$\max_{\forall i} (I_i^U)$ = maximum value from all the signals producing upper interference

$\max_{\forall j} (I_j^L)$ = maximum value from all the signals producing lower interference

The bandwidth optimization algorithm in PASSER II searches for the best phasing sequences and offset at each signal location to minimize the combined interference. The optimization process simultaneously considers progression on both directions. A one-way progression bandwidth can always be achieved at its maximum possible (G_{min}) with appropriate offset adjustments at each signal should this option be desired. To maximize the progression bandwidths for both directions, the offset and phasing of each signal should be carefully designed. For an intersection j with multi-phases, the interference for one direction is also related to the timing parameters for the other direction. Equations 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).

$$I_j^U(p) = [G_{min} - T_{mj} + T_{jm} - O_m(n) + O_j(p) + G_j] \text{ mod } C \quad (2)$$

$$I_j^L(p) = [T_{mj} + T_{jm} - O_m(n) + O_j(p) - S_j] \text{ mod } C \quad (3)$$

where

$I_j^U(p), I_j^L(p)$ = upper interference and the lower interference at intersection j with phase sequence p (only one could occur)

T_{mj}, T_{jm}	= travel times between intersections m and j
$O_m(n)$	= relative offset between direction a green time and direction b green time at signal m with phase sequence n
$O_j(p)$	= relative offset between direction a green time and direction b green time at signal j with phase sequence p
G_j	= direction a green time at signal j
S_j	= difference between the green times of intersections j and m in direction b
C	= cycle length

Equations 1 to 3 suggest that the bandwidth interference will likely increase with a larger number of signals to optimize, thus the system bandwidth will be reduced with more signals in a system. *Attainability* as described in Equation 4 is a useful measure to indicate how close the bandwidth is being achieved to its maximum possible bandwidth. When attainability is at 100%, the bandwidth is at its maximum.

$$A_B = \frac{B}{G_{min}} \times 100\% \quad (4)$$

The bandwidth optimization algorithm used in PASSER II can provide a guaranteed optimized bandwidth solution for two-phase signals. However, when signals have multi-phases, the optimal solution is not guaranteed.

The Proposed Signal Timing Approach

The proposed signal timing approach seeks an optimal bandwidth-based solution, i.e., to best possibly maximize progression band for the system. The proposed approach is outlined in the following steps:

1. Divide the system into sub-systems with each sub-system having 3 to 5 signals. Having 3 to 5 signals in a subsystem is purely heuristic, but should provide the maximum possible bandwidth as indicated by a high attainability value. Actual number of signals in a sub-system may vary as long as near 100% attainability values can be achieved. PASSER II is used to obtain the optimized bandwidth solutions for each sub-system. The process could eventually be automated using attainability as the selection criteria.
2. Combine the timings from the optimized sub-system solutions to form an initial timing solution. Primarily, the sub-system'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 sub-subsystems. A system progression band for the off-peak direction is not guaranteed after combining the sub-systems, however, the subsystem bandwidth or partial bandwidth will still remain because only the relationship between subsystems is adjusted.
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. The objective is to make the two progression bands from two neighboring sub-systems join by making some phasing adjustments. For example, a progression band connection can be improved by using lead/lag phasing or by switching the lead/lag sequence. It is likely the sub-system bandwidth be

affected after such phasing changes, but the impact is expected to be minor since each sub-system has only a few signals (e.g., 3-5 signals).

Case Study

System Description

A case study is presented in this section to illustrate the principles of the proposed signal timing strategy. The signal system is *Texas Avenue* in College Station, Texas. Figure 2 is a map of the system. Texas Avenue is a major north/south arterial serving many 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/hr) and 45 mph (73 km/hr). For demonstration purposes and easy plotting of the time-space diagrams, a speed of 40 mph (64 km/hr) was used to develop the timing and the time-space diagrams. 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 were derived based on the weekday A.M. peak period. 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 street 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 Drive and FM 2818. At George Bush Drive, 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 business centers as well as the Texas A&M campus. The existing system is operating at a 120-second cycle during the A.M. peak period.

PASSER II Optimization Solution

To ensure a fair comparison, the existing cycle length and the green splits at each intersection were kept unchanged for both the PASSER II optimization and the proposed signal timing approach using subsystems. To be consistent with the directional flow split, a 70/30 split was selected to perform the bandwidth optimization in PASSER II. Figure 3 is the resulting time-space diagram from PASSER II optimization for the entire system.

The system bandwidths for both directions were plotted in Figure 3. The PASSER II solution produced a northbound bandwidth of 15 seconds with an attainability of 45%, and a southbound bandwidth of 5 seconds 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 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. Examining the timing solution from PASSER II indicates that good partial progression bands do exist even though the system bandwidths are small. The timing solution is still considered as a decent solution, however, 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 Figures 4 to 6. The first step was to divide the entire system into smaller sub-systems. Division of the sub-system is usually based on consideration of the spacing between intersections, as well as the traffic flow characteristics, such as volume and queue conditions. For example, each sub-system should contain 3 to 5 signals. The optimized timing solution for such a sub-system can be easily obtained using PASSER II optimization software to achieve the maximum possible bandwidths

(i.e., with high attainability). Another consideration is that the sub-system 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 sub-system boundary at such a location 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, thus may fall outside of the progression band. However, these vehicles can be re-grouped and start progressing through the remaining signals in the next green band. Such a strategy is most effective while dealing with over-saturated or congested arterials. In our study case, the entire system was divided into three sub-systems. As a general observation, the intersections at George Bush Dr. and at Holleman Dr. were critical intersections with split phasing on the cross street and high turning traffic volumes coming from and going to the cross streets. There were also relatively large spacings at these locations. Once the sub-systems were formed, PASSER II was used to develop an optimized bandwidth solution for each sub-system. Figure 4 illustrates the resulting time-space diagrams for the three sub-systems, where the absolute maximum bandwidths were all achieved as indicated by the 100% attainability for all the sub-systems (intersections marked with ** in the figure have the minimum green times equal to the bandwidths).

The next step was to form a system progression band for the peak (northbound) direction. The bandwidth of the peak direction was controlled by the smallest bandwidth of all the sub-systems. In our case, the smallest northbound bandwidth was 38 seconds, which was given by the second sub-system (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 user 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 sub-

system 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 sub-system need not be changed. Only the offsets of signals in the other sub-systems need to be adjusted. In our case, the master controller is located at University Drive intersection (sub-system 1). Therefore, offset adjustments need to be made for the signals in sub-systems 2 and 3. As indicated in Figure 4 (a), the beginning band at University Drive, t_m is located at 88 seconds, which is obtained by subtracting the phase 1 time (northbound LT of $\phi_1 = 32$ seconds) from the offset O_m at University Drive. Subtracting the travel time between Walton Road and University Drive (calculated at 39 seconds), the beginning band of sub-system 1 at Walton Drive, t_o^1 is calculated at $88 - 39 = 49$ seconds. Subtracting further the travel time between George Bush Drive and Walton Road (calculated at 44 seconds), the beginning band for sub-system 2 at George Bush Drive, t_e^2 is $49 - 44 = 5$ seconds, or $120 + 5 = 125$ seconds. At present, the offset at George Bush Drive, O_7 is 105 seconds, and the beginning band (t_e^2) at George Bush Drive at current offset is obtained at 86 seconds by subtracting the phase 1 time of 19 seconds from the current offset ($105 - 19 = 86$ seconds). In order to create a northbound progression band, the beginnings of the sub-system bands need to be aligned, which would require the offset at George Bush Drive to add $125 - 86 = 39$ seconds. All the signals within sub-system 2 should be added with the same offset value of 39 seconds, which resulted in a new set of offsets for all the signals in sub-system 2. For example, the new set of offsets were 24 ($105 + 39 = 144 = 24$) seconds for George Bush Dr., 77 ($38 + 39 = 77$) seconds for Harvey Rd., and 71 ($32 + 39 = 71$) seconds for Holleman Dr., respectively. Similarly, the offsets in sub-system 3 also need to be adjusted in order to create a northbound system progression band. Figure 5 is the resulting time-space diagram from the above adjustments. As can be seen that the peak

direction bandwidth was maximized at 38 seconds. The off-peak direction was not guaranteed a system bandwidth as shown in this case. However, each sub-system retains its original partial progression band, which indicate that the traffic in the off-peak direction may only travel each sub-system without stopping. 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.

In fact, a similar peak direction bandwidth can be obtained directly from PASSER II by selecting an appropriate optimization strategy. For example, a 99/1 split of bandwidth optimization can be used in PASSER II to create a peak direction progression band. However, there will be no control on the off-peak direction, such as where a partial progression band might be created. Our proposed signal timing approach would give the traffic engineer complete control on 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 sub-system, 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 sub-system boundary intersections. The main purpose is to improve band connections for the off-peak direction by either using 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 on 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 (8). 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 was made on the lead/lag phasing sequence at the Walton Road 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 sub-systems 1 and 2 were better connected. If the change were made, it would require re-optimization of the timing for each sub-system. Similarly, a phasing sequence change at Holleman Dr. intersection would also improve the band connection for subsystems 2 and 3. Figure 6 shows the final timing plan after these phasing changes were made. As shown, a 10-second progression band was created for the off-peak direction while the peak direction progression band of 38 seconds was retained. Compared to the original PASSER II solution with the bandwidths of 15 seconds and 5 seconds for the two directions, our proposed approach resulted 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 achieved the maximum progression band for the peak direction, and also resulted in a better system band for the off-peak direction. In addition, our proposed approach resulted in improved partial band relations for the particular case studied. Figure 3 shows that PASSER II produced a decent timing solution as indicated by the partial band. However, for each direction, PASSER II resulted in the first partial band that lags the system band, and the second partial band that leads the system band. This 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 further progress through the system. As for the timing from our proposed approach shown in Figure 6, the partial band for the off-peak direction can better progress the traffic, 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. Again, this case may be particular to the study system.

The proposed signal timing approach was illustrated primarily as a heuristic approach, but it showed 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 effective especially when the signal system has a large number of signals, say more than 10 signals. With a signal system of large number of signals, PASSER II or other optimization software would 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 sub-systems and the entire system. A good rule of thumb of system partition is to have 3 to 5 signals in a subsystem or as long as high attainabilities can be achieved for the subsystem. The subsystem boundaries need to be selected where critical intersections are located as well as large spacing exists between the adjacent intersections.

Simulation Evaluation

More detailed evaluations on the timing solutions presented previously were conducted using 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 was to select the split phasing sequence so that the left-turn traffic coming from the cross street could be better progressed. 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, i.e., the progression band immediately follows the left-turn traffic.

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

Figure 7 illustrates the percentage of stops and travel speed on each link in both the northbound and southbound directions. In general, improved operations were achieved on most of the links in the northbound direction with the proposed timing solutions, as indicated by the lower percentage of stops and higher travel speeds. For the southbound direction, the initial proposed timing solution (shown as Pro1) resulted in distinct increases in the percentage of stops and consequently the drop on travel speeds on the two links (link 8-7 and link 5-4). These are the direct impact resulted from discontinuation of the progression band at the subsystem boundaries (Walton Road to George Bush Drive; and Holleman Drive to Brentwood Road).

Figure 8 shows the speed results in each direction for the three timing solutions. Figure 8 (a) shows the average speeds for all the vehicles, while Figure (b) shows the speeds for arterial through traffic only. As shown in Figure 8 (a), the two timing plans from the proposed approach yielded higher travel speed for the northbound direction. However, the initial proposed timing (noted as Pro1) resulted in lower travel speed for the southbound direction. Nevertheless, the average travel speed for both directions showed improvement over the initial PASSER II solution. The initial proposed timing resulted in speed increase of about 3%, and the timing with final adjustments (shown as Pro2) resulted in an increase of about 6%.

Travel speeds for the arterial through vehicles shown in Figure 8 (b) were 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 travelling through the entire system. About 50 such bus-type vehicles per hour were coded in simulation for each direction, with each vehicle entering the system randomly. The average speed of such bus-type vehicles was used to estimate the travel speed for the through vehicles. As shown in Figure 9, the proposed timing solutions generally showed more significant improvements for the through traffic. With the initial proposed timing (noted as Pro1), the average speed for both directions increased by about 3%, but the improvement was about 15% with the final proposed timing solution (noted as Pro2). The results indicated that the proposed timing solutions resulted in significant benefit to the arterial through traffic. The proposed bandwidth-oriented signal timing approach may have resulted in increased delay to the non-through traffic movements in this case. The results also indicate that PASSER II incorporates some delay minimization component besides the bandwidth optimization technique. When arterial through traffic is significant, our proposed approach would produce more efficient signal timing solutions.

Summary and Conclusions

Unlike the system bandwidth optimization algorithm used in PASSER II, a signal timing approach based on system partition technique was proposed to develop bandwidth-oriented timing solutions. This approach would allow maximum progression for the peak direction by providing the maximum possible progression band. Progression in the off-peak direction is also controlled by providing partial progression band at each subsystem. By doing this, the location and place to progress and stop traffic is clearly known. The two timing approaches were evaluated using microscopic simulation model. The following is a summary of the major conclusions:

- In general, PASSER II produces good timing solutions even with a large number of signals in a system. This is best illustrated by the partial band resulted from the delay and stop minimization algorithm used in PASSER II.
- The proposed timing approach of creating subsystems, has the potential to improve the bandwidth optimization solutions generated by bandwidth algorithms such as used in PASSER II. 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 at 38 seconds and 10 seconds for the two directions, compared to 15 seconds and 5 seconds from PASSER II when optimizing the entire system.
- Evaluations using 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%.

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- Although the proposed approach is primarily heuristic, it can be easily applied by traffic engineers with bandwidth optimization software such PASSER II, and some user-friendly time-space diagram generation software such as Synchro. It also provides valuable information to enhance existing bandwidth optimization algorithms. For example, instead of optimizing the entire system at the same time, optimization may be performed the sub-systems before producing a system timing solution.

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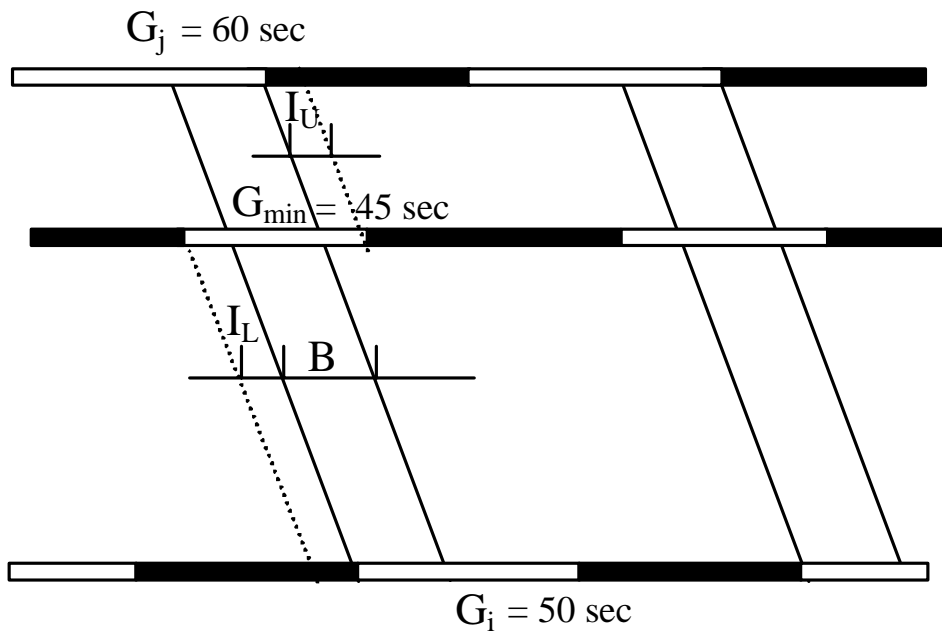


Figure 1 Illustration of Bandwidth Optimization Concepts

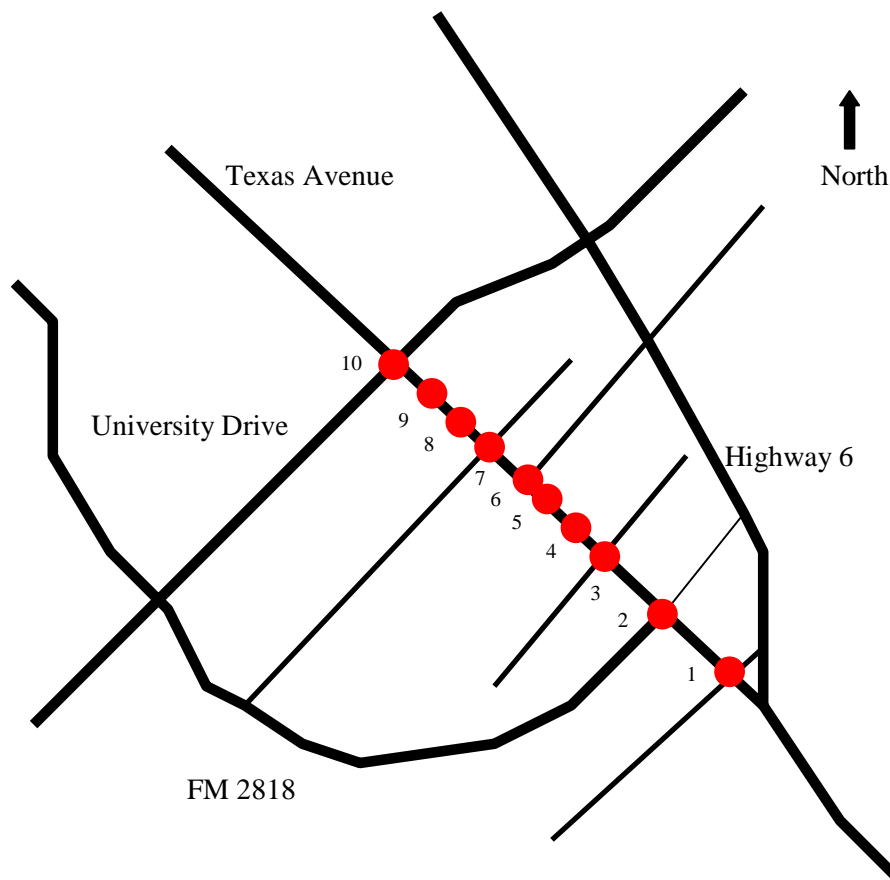


Figure 2 Signal System Map – Texas Avenue

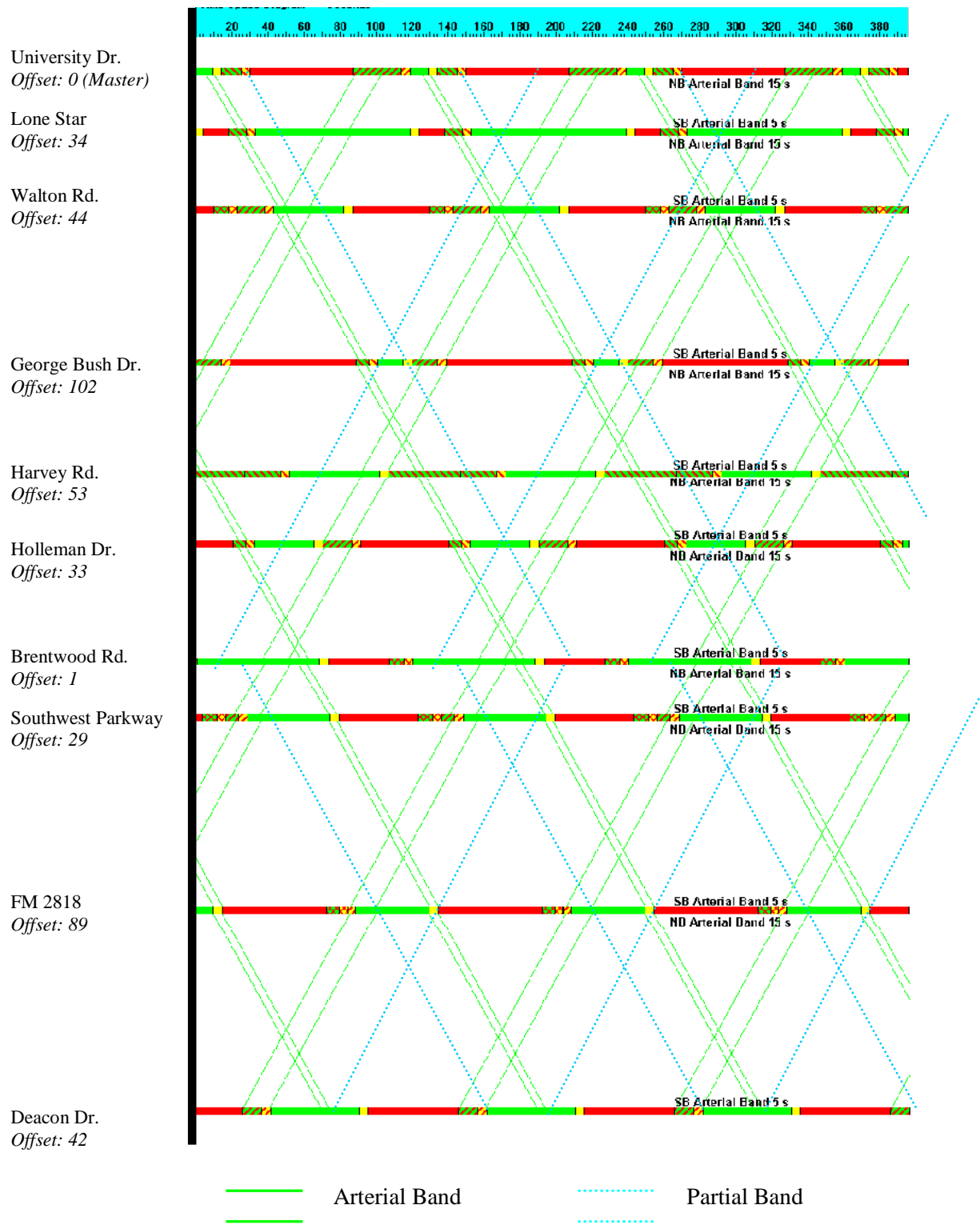
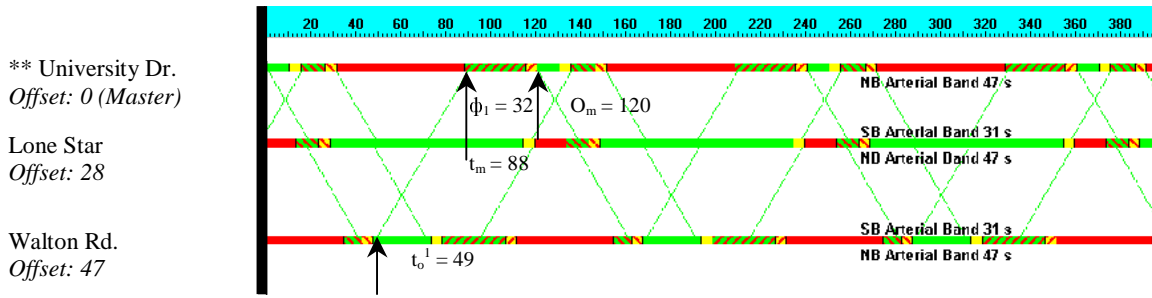
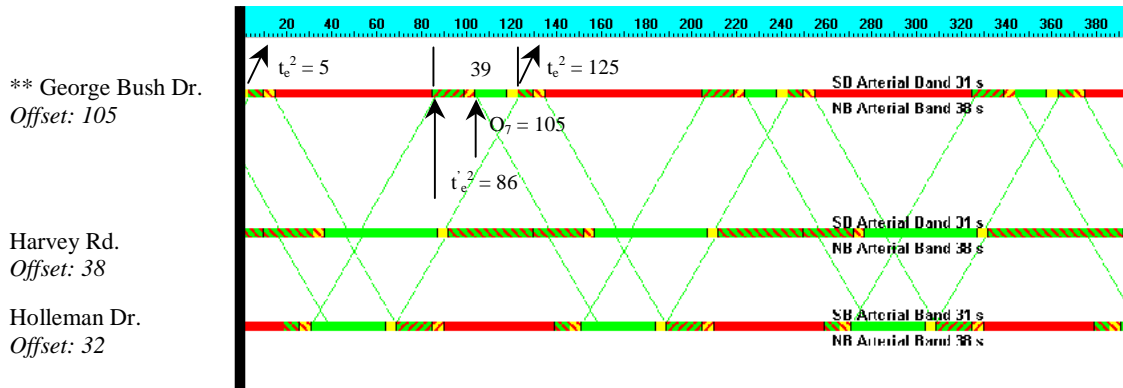


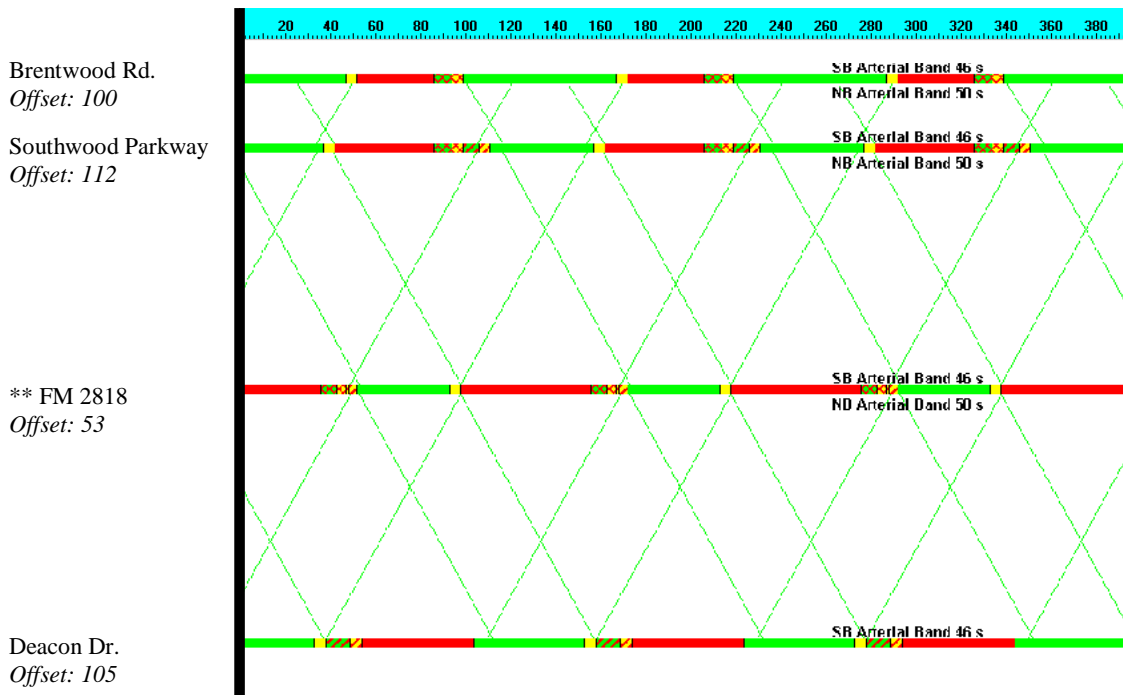
Figure 3 Time-Space Diagram from PASSER II Solution



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



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



(c) Time-Space Diagram for Sub-System 3

Figure 4 Optimized Time-Space Diagrams for the Sub-Systems

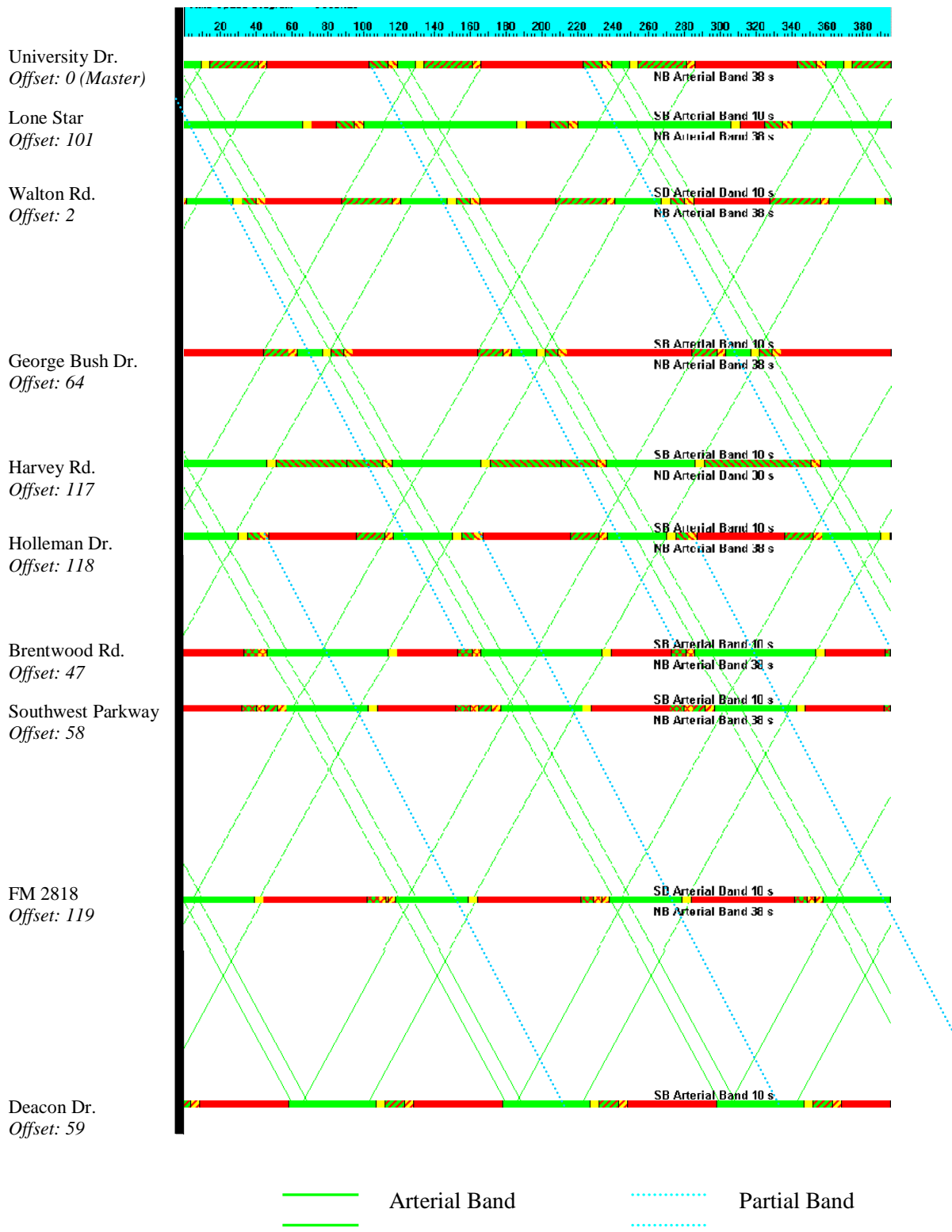
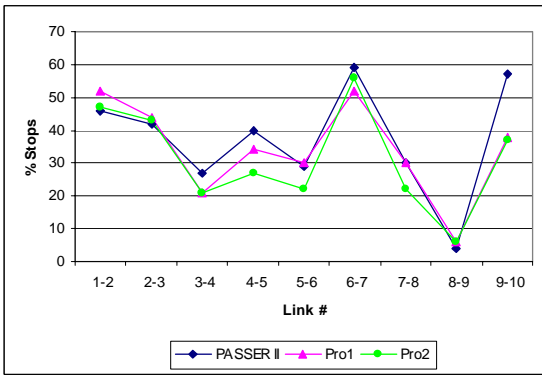
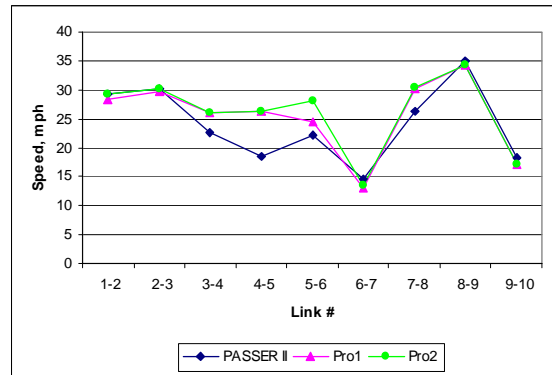


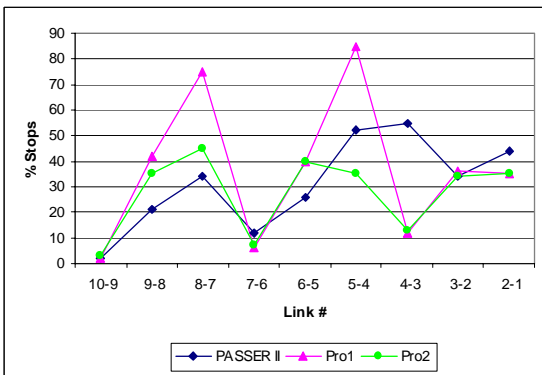
Figure 6 Final Time-Space Diagram with Adjustments



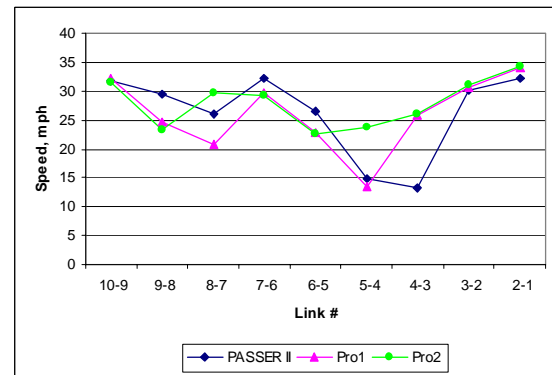
(a) Average Stops (%) for the Northbound Links



(b) Average Speeds for the Northbound Links

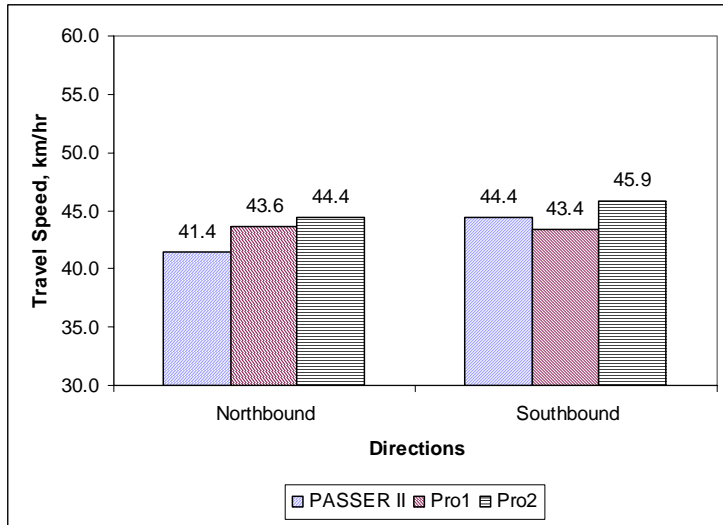


(c) Average Stops (%) for the Southbound Links

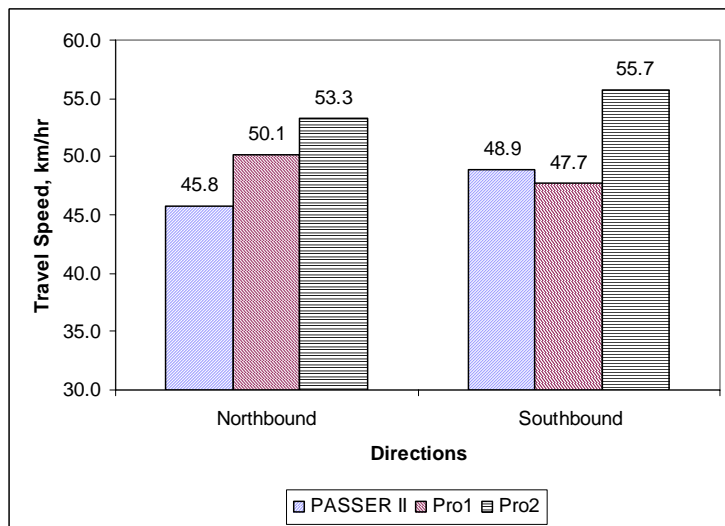


(d) Average Speeds for the Southbound Links

Figure 7 Stops and Speeds by Link



(a) Average Speeds of All Vehicles in Both Directions



(b) Average Speeds for Arterial Through Vehicles

Figure 8 Average Speeds for the Study Scenarios

Table 1
Summary of Traffic and Control Characteristics

Intersection #	Cross Street Name	Spacing (meters)	Main Street Left Turn Phasing	Cross Street Left Turn Phasing
1	Deacon Dr.	–	Prot./Perm.	Split
2	FM 2818	1056	Prot./Perm.	Split
3	SW Parkway	1006	Prot./Perm.	Prot./Perm.
4	Brentwood Rd.	282	Prot./Perm.	Prot./Perm.
5	Holleman Dr.	610	Prot.	Split
*6	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.

Notes: 1. Prot. – Protected; Perm. – Permitted;

2. Southbound through (phase 2) at Intersection 6 is uncontrolled.

References

1. Texas Transportation Institute, *PASSER II-90 User's Manual*, 1990
2. University of Florida, *TRANSYT 7-F User's Manual*, Version 9.1, 2001
3. Trafficware, Inc., *Synchro User's Manual*, Version 5, 1993 - 2001.
4. Federal Highway Administration, *CORSIM User's Manual*, Version 5.2, 2000
5. Yang, X.K, *Comparison Among Computer Packages in Providing Timing Plans for Iowa Arterial in Lawrence, Kansas*, Journal of Transportation Engineering, Volume 127, Issue 4, pp.314-318.
6. Brooks, W.D. *Vehicular Traffic Control, Designing Arterial Progressions*; IBM, Unpublished Materials.
7. Messer, C.J., Whitson, R.H., Dudek, C.L., and Romano, E.J. *A Variable-Sequence Multiphase Progression Optimization Program*. HRR 445, pp. 24-33, 1973.
8. Buckholz, J.W. *The 10 Major Pitfalls of Coordinated Signal Timing*; ITE Journal, August 1993, pp. 27-29.