Improved Manual Methods of Coordinated Signal Timing

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INTRODUCTION

This paper addresses the problem of finding good signal timing strategies for interconnected signals along an arterial street. The discussion focuses on improvements in the existing manual techniques of displaying and developing signal timing plans.

Fig. 1 shows a common arterial diagram and a time space diagram. The trajectory shown is that of a vehicle travelling unimpeded along the arterial. The speeds shown might, for instance, be the

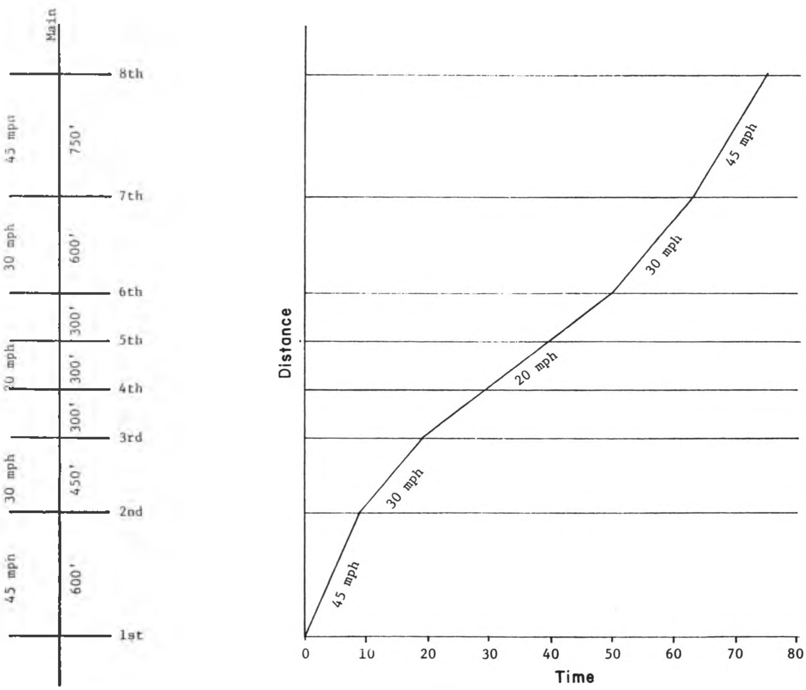


Fig. 1. A typical arterial diagram and time-space diagram. Note that the vertical axis is distance.

applicable speed limits. Note that as the speed of the vehicle changes, the slope of the trajectory also changes. This change in slope is somewhat inconvenient to draw since, for each speed, the slope of the trajectory must be calculated and the angle plotted.

This inconvenience is avoided by the method shown in Fig. 2.

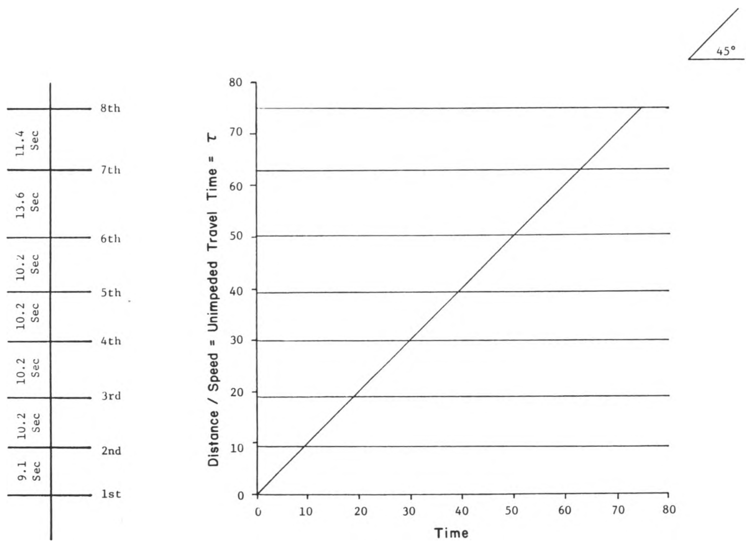


Fig. 2. An arterial diagram and time-travel time diagram. Now the vertical axis is unimpeded travel time, so the trajectory of an unimpeded vehicle is a 45° line.

Here, distance/speed (or unimpeded travel time) is plotted instead of distance. The advantage is that now the trajectory of an unimpeded vehicle is a 45 degree line. A 45 degree line is easy to draw using graph paper or a 45 degree triangle. Unimpeded travel time vs. time plots will be used throughout the rest of this paper.

THE IDEAL OF "PERFECT" PROGRESSION

The objective of most signal timing schemes is to come as close as possible to the "perfect" progression shown in Fig. 3. Diagrams such as

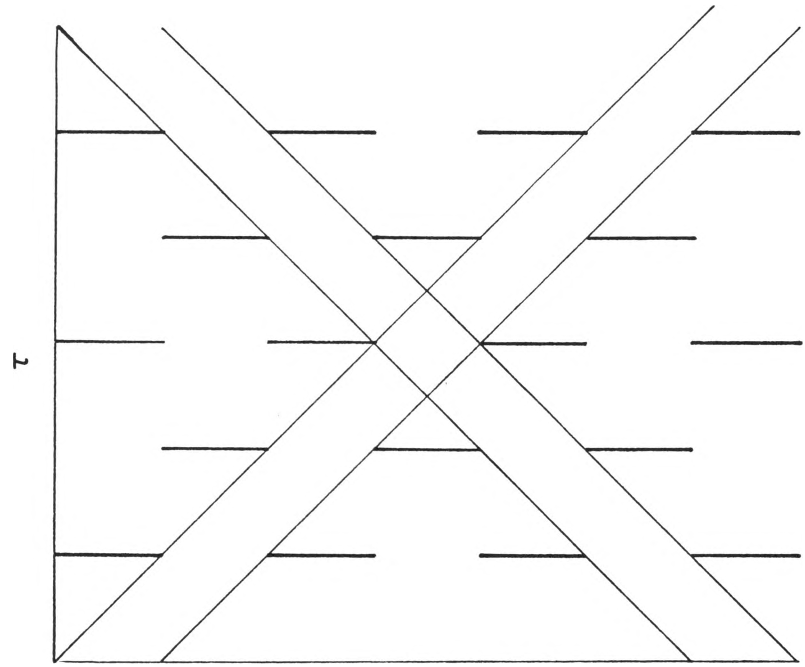


Fig. 3. "Perfect" progression.

this one appear often in textbooks and other instructional material, as though such a scheme is a commonly used one. For such a scheme to work, however, the unimpeded travel time between intersections, called τ must be 1/2 the cycle length, as in Fig. 4. But, typically, τ is between

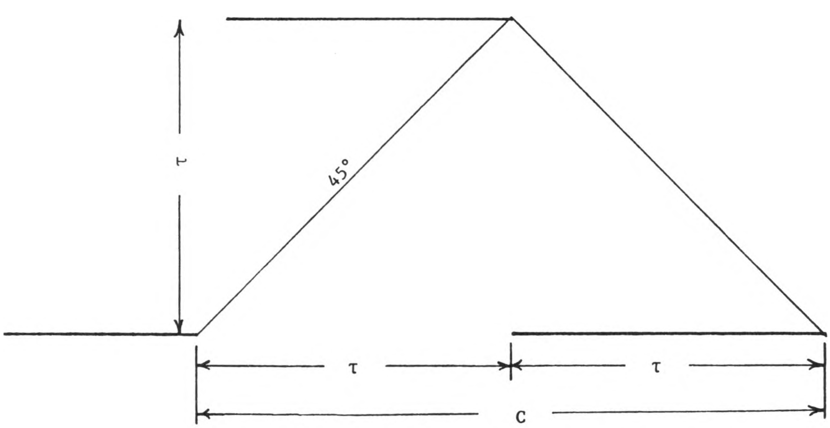


Fig. 4. For "perfect" progression, $C = 2\tau$.

about 10 and 20 sec. For example, in downtown Lafayette (and many other Indiana cities), the block spacing is about 330 ft. The unimped travel speed is 20 mph, so τ = 11 1/4 sec. On Northwestern Avenue in West Lafayette, direct measurement shows that r is 20 sec. For "perfect" progression these travel times would yield cycle lengths of 22 1/2 and 40 sec., respectively.

In off-peak periods, these cycle lengths might be long enough to carry the vehicular traffic. (On Northwestern Avenue, in fact, a 40-sec cycle would handle vehicular traffic.) But these cycle lengths do not meet other requirements. In particular, the short phase lengths would not meet pedestrian initial and clearance interval requirements as stated in the Indiana Manual on Uniform Traffic Control Devices [1]. For example, on Northwestern Avenue at Grant Street, the sum of the pedestrian walk plus flashing don't walk on the two phases in 60 sec. If all the signals on Northwestern Avenue are to share the same cycle length, then, the system cycle length must be at least 60 sec. But with a 20-sec travel time and a 60-sec cycle length, "perfect" progression cannot be achieved. The question is, when "perfect" progression is impossible, what is the best signal timing?

The usual method of solving this problem manually is the maximum bandwidth method. Fig. 5 shows a bandwidth solution for an ex-

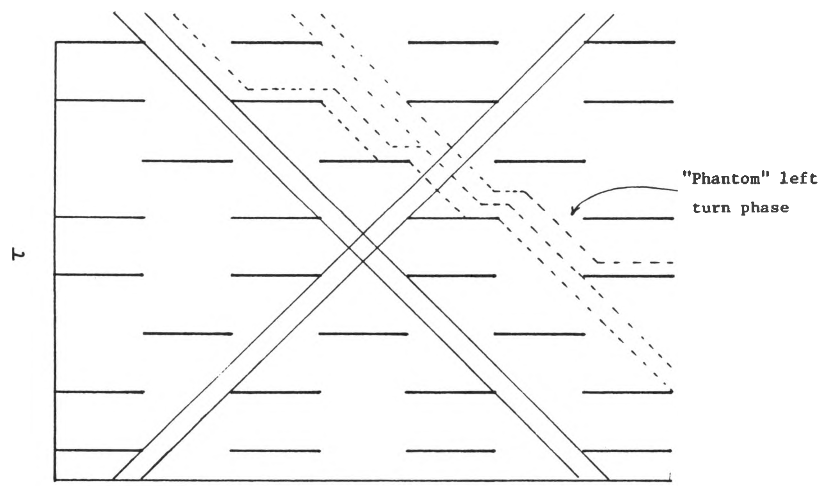


Fig. 5. Formal maximum bandwidth solution for an extended version of Northwestern Ave., for which τ = 20 sec, C = 60 sec. Solid lines - through bands; broken lines - platoons when traffic flow is twice the through band. Note the interrupted flow.

tended version of Northwestern Avenue. Note that the through bands in this case are each 10 sec. long, which is only 1/3 of the available green time. As long as traffic is light and the platoons fit within the through band, everything is all right. Delays are small and stops are few. But if, for example, the traffic is heavy enough that platoons take 20 sec. to clear an intersection, the bandwidth solution no longer works well. The broken lines show what happens: the second half of the platoon entering the first signal stops at the next three signals. By the time this half finally gets through several consecutive greens, it has delayed the first half of the next platoon, which must also stop at several consecutive signals, and so forth. This pattern repeats itself over and over again. This kind of interrupted flow is nothing like "perfect" progression, of course. The average delay is 10 sec per signal per vehicle, and the average number of stops is 2/3 stop per signal per vehicle.

"PHANTOM" LEFT TURN PHASES

Before considering other timing plans, note the arrow indicating a "phantom" left turn phase at one of the signals. During the last 10 sec of green at this signal, no through traffic should be using the intersection. This creates an opportunity for opposing left turn vehicles to make their turns, almost as though a left turn phase had been provided. The advantage, of course, is that no extra signal heads or other equipment is needed, making the signal cheaper to install and maintain. Also, a left turn phase need not be provided all day just because it is needed part of the day. Most of the available signal timing optimization computer program do not model opposed left turns accurately, and so do not provide for phantom left turn phases. But, if the need and the opportunity are recognized, the phase can be included by hand.

ONE-WAY PATTERNS

Consider the problem of finding a better pattern for Northwestern Avenue. Newell [2] proved that, under traffic flow near but not quite at saturation (he called this "heavy" flow), the best solution is a one-way pattern between each pair of signals. An example of such a pattern is shown in Fig. 6. In this case, the top two signals are progressed for down traffic, the 2nd and 3rd for up traffic, the 3rd and 4th for down traffic again, and so forth. The average delay is 10 sec per signal per vehicle, and 1/2 stop per signal per vehicle, regardless of the flow. Note that the delay is the same as with the maximum bandwidth solution earlier when the flow was 2/3 of the capacity of the green, but there are fewer stops with this scheme, making the one way pattern the better solution. As it turns out, when flows are less than about 1/2 of capacity, the maximum bandwidth solution is better, otherwise the one-way pattern is better.

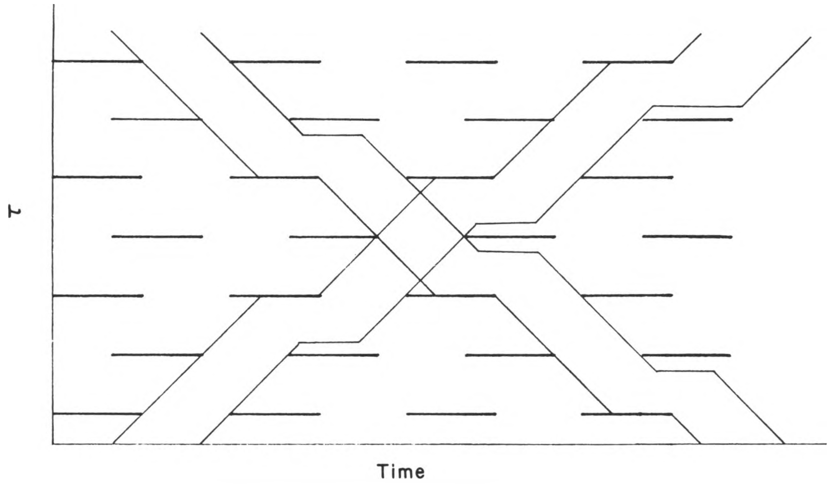


Fig. 6. A "heavy traffic" solution for Northwestern Avenue. (This is alternating one-way solution.) This solution gives least delay and stops if band nearly fills green time. Note there is no through band.

The pattern shown in Fig. 6 could be called an "alternating one-way" solution. As long as the flows in the two directions are equal, this pattern provides for one-way progression between each pair of signals. Another pattern in this family, for instance, is a pure one way solution. In fact, despite its apparent unfairness to the non-progressed direction, the pure one-way pattern gives least delay when the flows in the two directions are heavy but unequal or when there are more turning movements in one direction than in the other.

DOWNTOWN SIGNALS

The problem of timing signals on a two-way street in a downtown area yields a different solution. Typically in this case, τ is a small fraction of the cycle length, at most about C/4. Fig. 7 shows an example for which r is 1/6 of the cycle length. In this situation, the maximum bandwidth solution is a triple alternate pattern as shown. The bands are each 10 seconds wide, which give a maximum flow of about 180

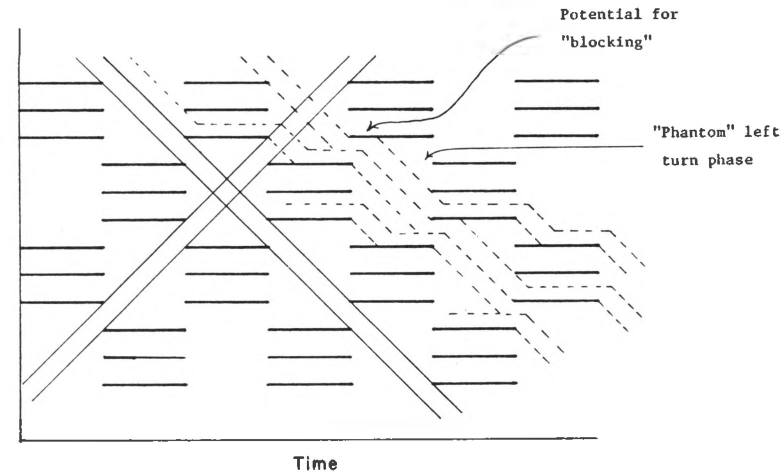


Fig. 7. Maximum bandwidth solution for a typical downtown two-way street (τ = 10 sec, C = 60 sec). This is a triple alternate pattern. Solid lines - through bands (max. flow = 180 veh/hr/lane); broken lines -flow is twice the through band, resulting in interrupted flow.

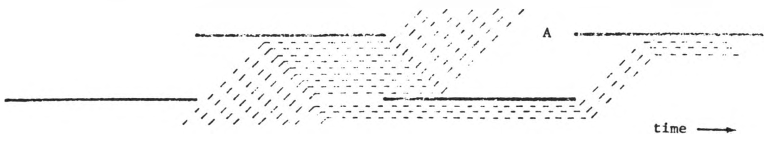
veh per hr per lane. This flow is quite small and is often exceeded. Fig. 7 shows that if, for instance, there are twice as many vehicles as can fit in the through band, the result is interrupted flow. Also, there is a potential at every third signal for "blocking."

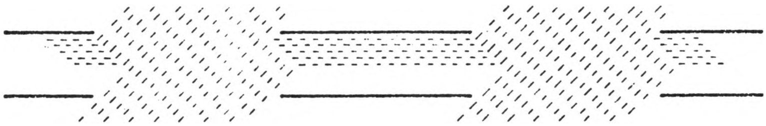
Blocking occurs when, as in Fig. 8, the green time at a signal is more than sufficient to serve all the vehicles in the block upstream, but the upstream signal prevents vehicles from utilizing the last part of the green. As shown in the lower part of Fig. 8, a different choice of offset (such as 0 offset, i.e. simultaneous timing) can prevent blocking. As a rule of thumb blocking can occur if r is less than about 1/4 - 1/6 the cycle length. Most signal timing optimization programs do not model blocking, and thus cannot prevent it. But it is easy to check for blocking manually, and such checking can prevent a bad situation.

Blocking occurs when a signal serves all the vehicles in the block upstream of it and has some green time left, but no vehicle can utilize it. A loss in capacity of the intersection results.

A different choice of offset can eliminate it.

Signal timing optimization programs do not model blocking and therefore cannot prevent it. The signal system should be checked for blocking manually (an easy thing to do).





BLOCKING PREVENTED

Fig. 8. Blocking.

A better pattern for fairly heavy flows on a 2-way CBD street is shown in Fig. 9. Here all signals along a street turn green

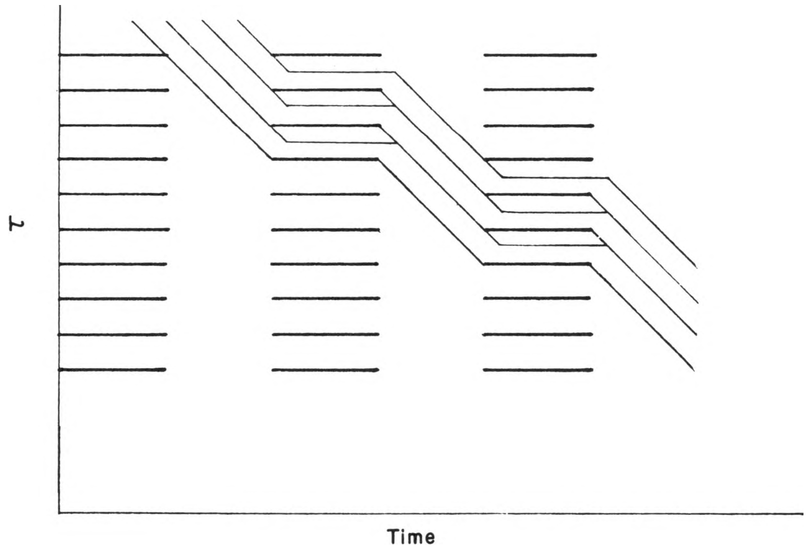


Fig. 9. Heavy traffic solution for typical downtown two-way street (simultaneous pattern). Note that blocking cannot occur because queue lengths do not exceed about 1/2 block length.

simultaneously. Blocking cannot occur because queue lengths never exceed about half a block length. Note also that no through band exists in either direction, but that the lack of blocking prevents the possible loss in capacity caused by the triple alternate pattern. Under the simultaneous pattern shown in Fig. 9, the average delay is 10 sec per signal per vehicle and the average number of stops is 1/3 stop per signal per vehicle. Under the triple alternate solution, both the delay and number of stops go to infinity if the flow exceeds 2/3 of the maximum allowed by the green time. With flows less than 1/3 of capacity, the triple alternate system gives almost no delay and no stops. The best pattern changes dramatically with different levels of flow.

SUMMARY

Traffic signals on arterials can be timed manually, but no single pattern is likely to work well under all conditions. If traffic is light, then a maximum bandwidth solution will most likely be satisfactory. If traffic is heavy, then the solution depends on whether the between intersection travel time is greater or less than about C/4. If the travel time is greater, a one-way pattern should be used. If it is less, than a simultaneous pattern should be used to prevent blocking. With any scheme, phanton left turn phases should be considered before actual left turn phases are installed.

REFERENCES

1. *Indiana Manual on Uniform Traffic Control Devices*, Indiana Department of Highways, 1975.
2. Newell, G.F., 'Traffic Signal Synchronization for High Flows on a Two-Way Street,' Proc., Fourth Int'l. Symp. on the Theory of Traffic Control, Karlsruhe, Germany, pp. 87-92, 1968.