



Chapter 24: Signal Coordination for Arterials and Networks

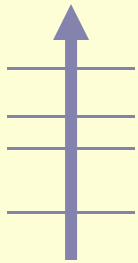
Chapter objectives: By the end of this chapter the student will:

- Be able to explain how offset can affect the flow of traffic on an arterial with signalized intersections
- Know how to include the effect of standing queues in offset determination
- Be able to determine signal offsets on one-way streets
- Be able to meet the goal of coordinating signals on 2-way streets
- Know how to manually coordinate offsets of signals in a small network of signalized intersections
- Understand the maximum greenband concept
- Be able to describe typical coordinating schemes for 2-way streets

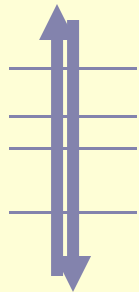
Purpose of signal system

The purpose of signal system (for coordination) is determined by:

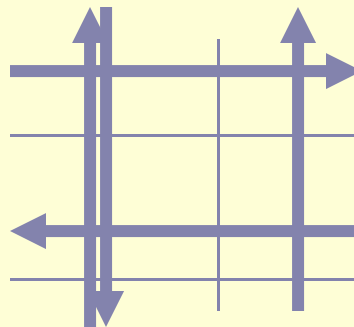
- ❑ The physical layout of the street system (see below)
- ❑ The major traffic flows → Which direction should be favored? One-way → Obvious, Two-way → Depend on the day, Network → which streets are favored?
- ❑ For what purpose are the signals to be coordinated? → What is the objective?
E.g., Maximize bandwidth (good for one-way or two-way during peak periods),
Minimize delay, Minimize the number of stops, Minimize combination of stops and delay (last three objectives are used for networks.)



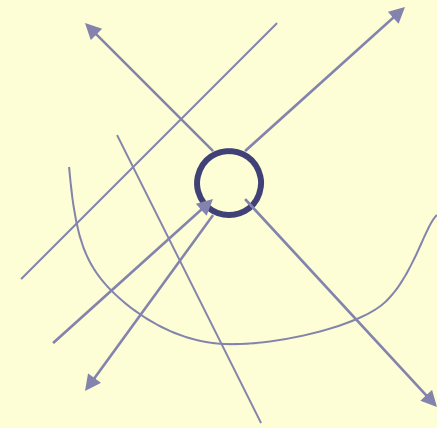
One-way
arterial



Two-way
arterial



Network





Benefits

The prime benefits of coordination are:

- Improvement of service provided (meaning, higher flow and smoother flow through the set of signalized intersections)
- Reduction in user costs by reduced number of stops and associated delays

A typical user cost model use looks like this:

$$\text{Cost} = A * (\text{total number of stops}) + B * (\text{total delay}) + \text{Other terms}$$

➤ Other benefits include:

- Conservation of energy (Less fuel)
- Preservation of the environment (Less pollutants)
- Maintenance of preferred speed (Discouraging speeding)
- Maintenance of well-formed platoons (Providing gaps to side streets)
- Stop fewer vehicles (Less # of queued vehicles within the available storage)



Factors lessening benefits of coordination

● Sometimes coordination just doesn't work because of:

✓ **Inadequate capacity** → Serious issue. Cannot send vehicles more than the facility can handle.

✓ **Existence of substantial side frictions** → Curb parking, loading vehicles, double parking, multiple driveways → these vehicles disturb the main flow platooning and reduce the capacity of the approach

✓ **Complicated intersections, involving multiphase control** → Traffic circles (not roundabouts because roundabouts usually do not have signals), five-leg intersections, large intersections that require long cycle lengths (May use a double cycle)

✓ **Heavy turn volumes, either into or out of the street (affecting platoon structures)**

■ Heavy turn-out → impede platoons or destroy their structure

■ Heavy turn-in → less sharp changes in stop and delay curves



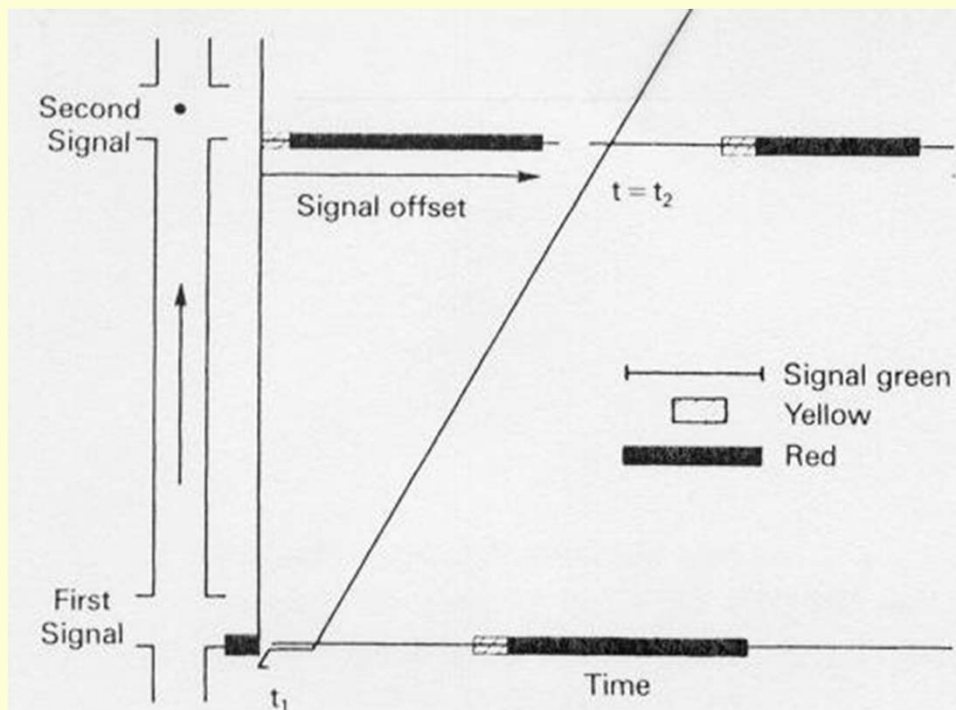
Exceptions where coordination is difficult, if not impossible

- **A troublesome intersection in the middle of the system (longer cycle length, more phases) →** Like University Parkway & State St. in Orem which carry considerably higher approach volumes than other intersections on State St. → A double cycle may be used.
- **Large circles →** Many found in Washington, D.C.
- **“Critical intersections” →** they cannot handle the volume delivered to it at any practical cycle lengths. → One method is to coordinate upstream signals such that approach volumes more than the critical intersection can handle are not released from the upstream intersections.

24.1 Basic Principle of Signal Coordination

24.1.2 The time-space diagram and ideal offsets

Where signals are relatively closely spaced, it is necessary to coordinate their green times so that vehicles may move efficiently through the set of signals. → An attempt to reduce wasted green time.



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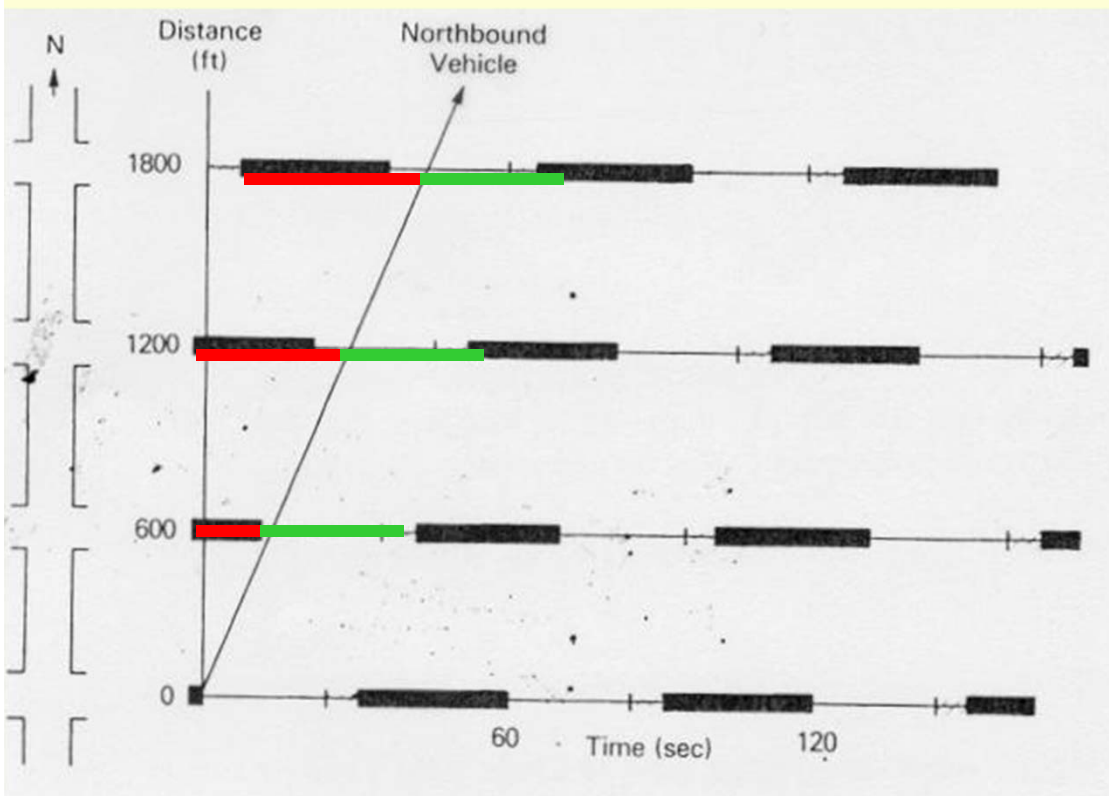
Common practice is to coordinate signals less than one-half mile apart on major streets and highways.

Two important facts:

- ❖ All signals must have the same cycle length. (24.1.1)
- ❖ Signal offset (or simply “offset”) is the heart of signal coordination. → Pay attention to its definition. 6

24.1.2 The time-space diagram and ideal offsets

- Time-space diagram is simply the plot of signal indications as a function of time for two or more signals
- The T/S diagram is SCALED with respect to distance to ease plotting vehicle positions as a function of time



“Ideal offset” defined:

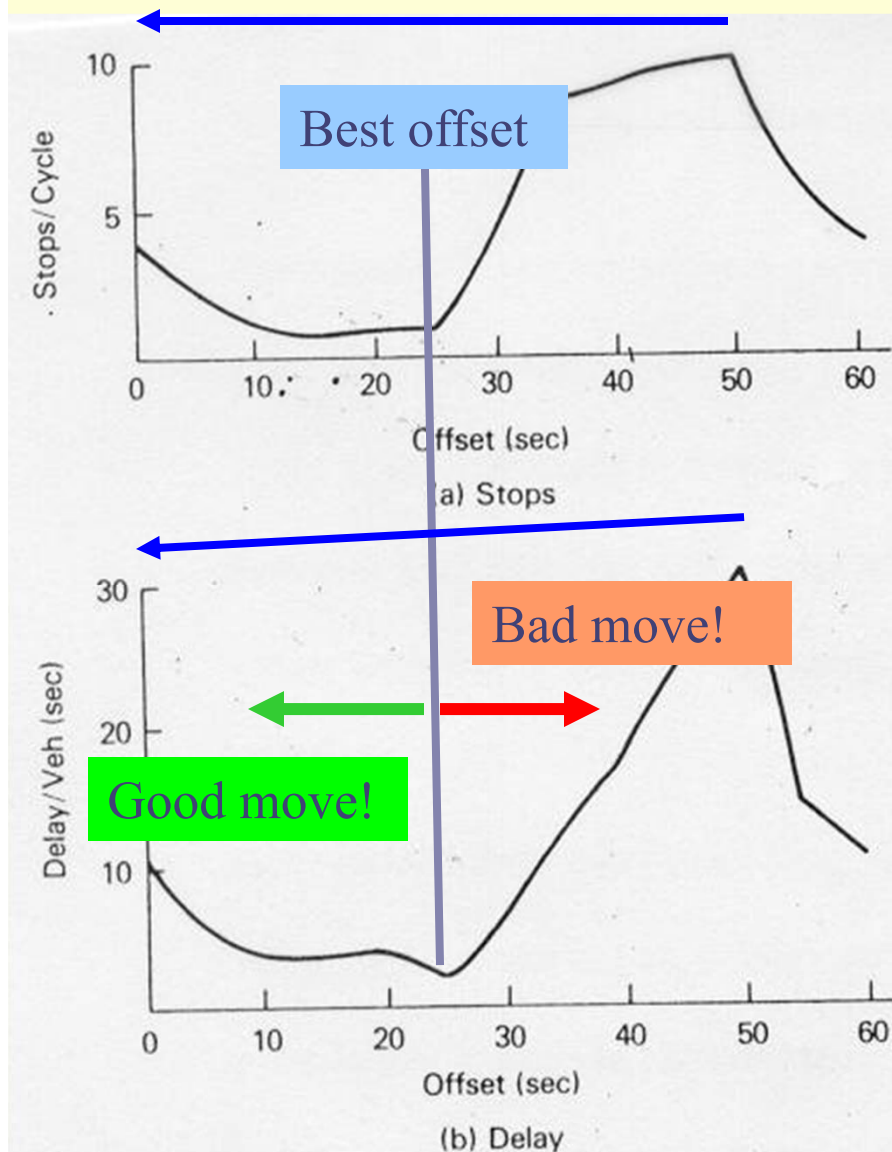
$$t(ideal) = \frac{L}{S}$$

$t(ideal)$ = ideal offset, sec

L = block length, ft

S = vehicle speed, fps

Fig 24-2. The effect of a poor offset

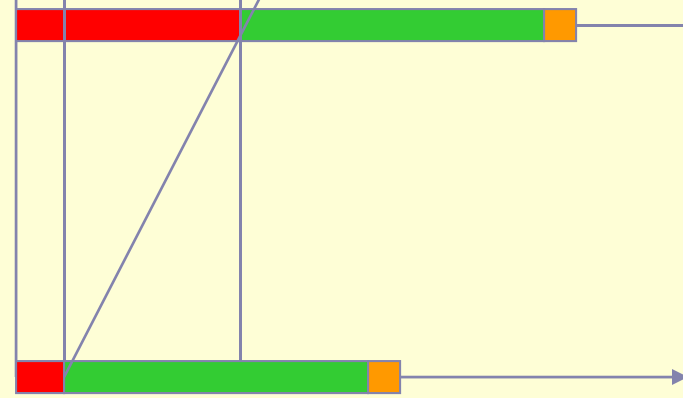


600 ft block
600 vph in two lanes
all through traffic
free speed 24 mph
50-50 split
60 sec. cycle length

(Actual speed,
say 20 mph)

$$\text{Offset} = 600 \text{ ft} / 29.4 \text{ fps} = 20.4 \text{ sec}$$

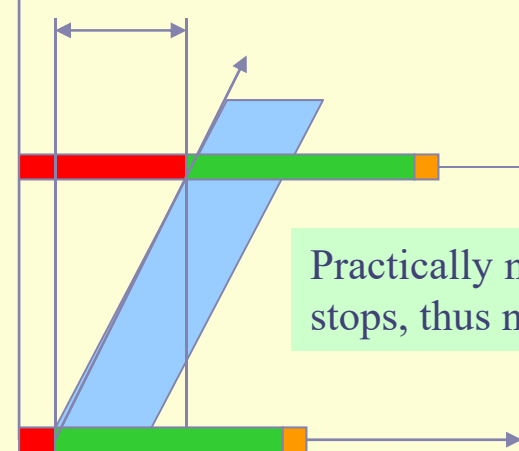
20 mph =
29.4 fps



Without any standing queue

Fig 24-2. The effect of a poor offset (cont)

Offset = $600 \text{ ft} / 29.4 \text{ fps} = 20.4 \text{ sec}$



Practically no vehicle stops, thus no delay.

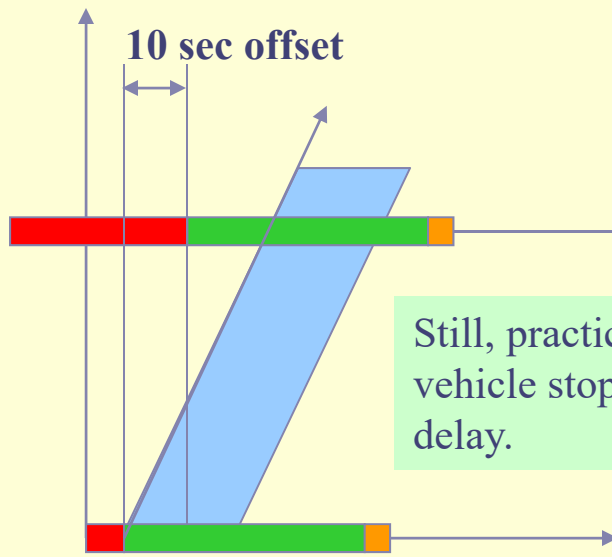
□ On the average we have:

$$600 \text{ vph} / 60 \text{ cycle/hr} = 10 \text{ veh/cycle}$$

that is, 5 veh/cycle/lane

□ If we assume that the average headway is 2.2 sec, we need:

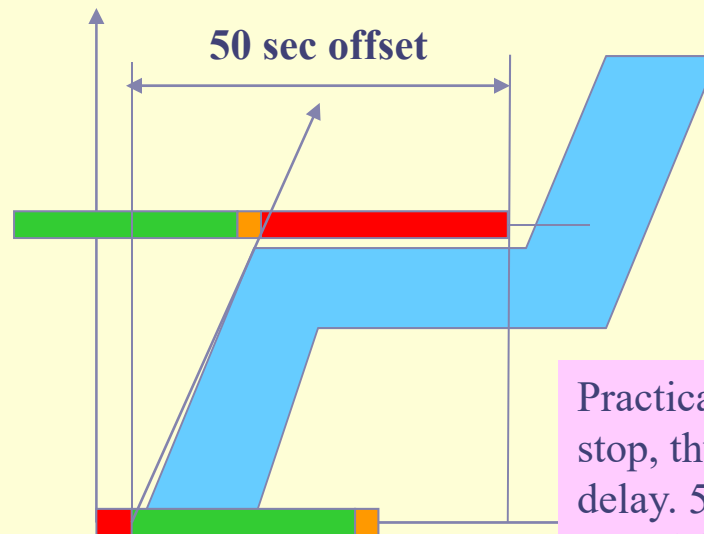
$$2.2 \times 5 \text{ veh} = 11 \text{ sec green band at minimum}$$



10 sec offset

Still, practically no vehicle stops, thus no delay.

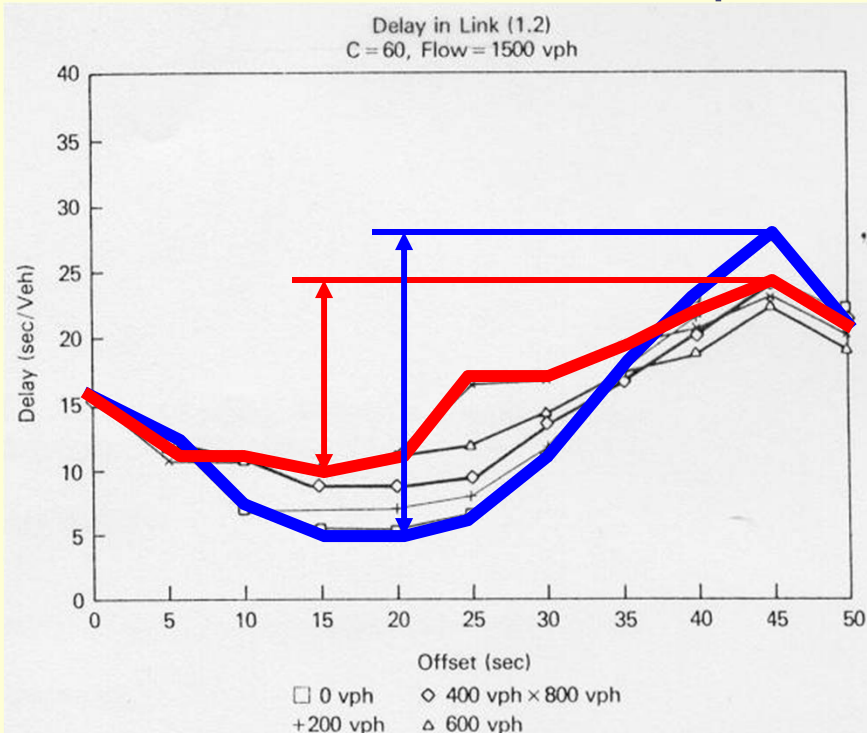
Offset = 10 sec



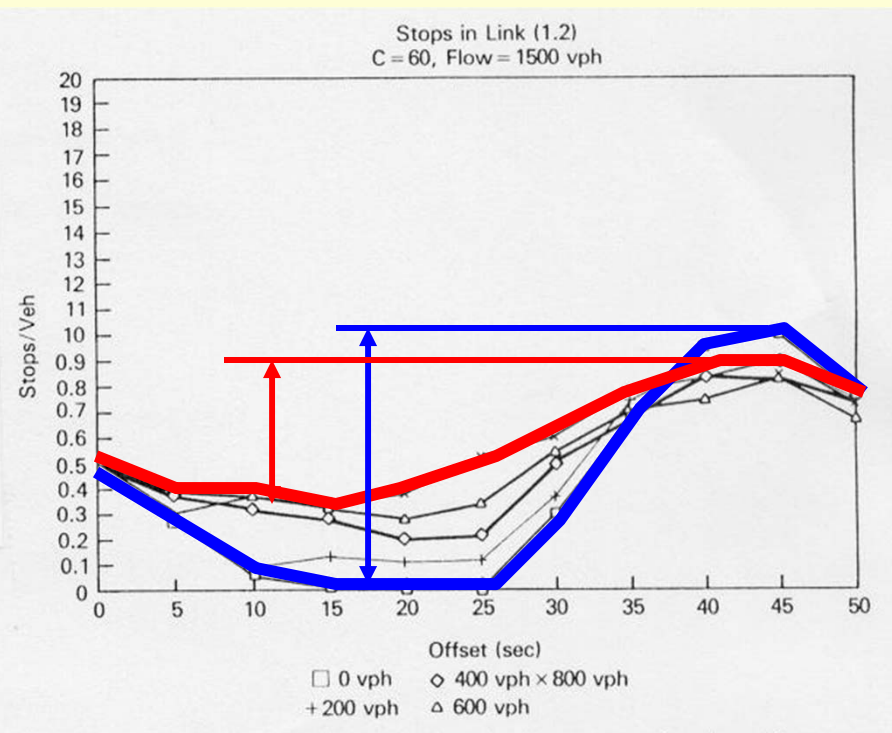
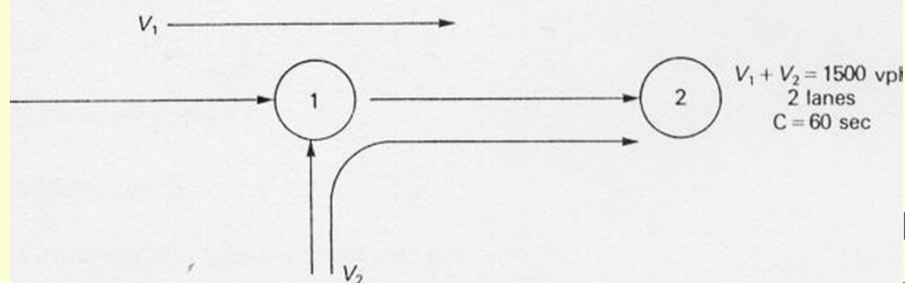
50 sec offset

Practically all vehicles stop, thus a lot of delay. 5 veh/lane → 10 veh/approach, 30 sec delay per vehicle

Heavy turn-ins and outs reduce the benefit of coordination (this was eliminated in the 3rd edition, but it is important to know this.



(a) Delay as a function of offset for various turn-in volumes V_2



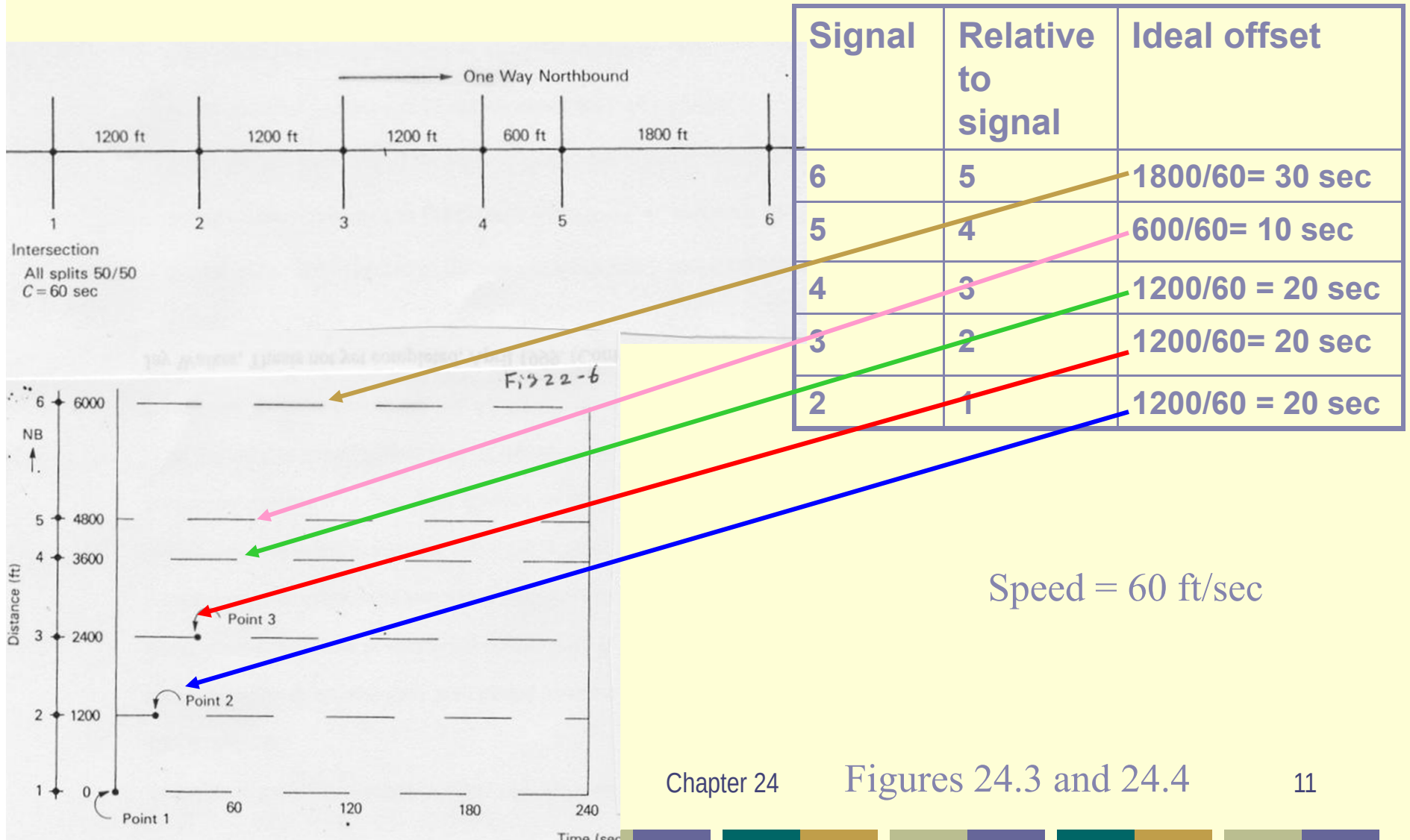
(b) Stops as a function of offset for the same turn-in volumes V_2

— 0 veh from the side street

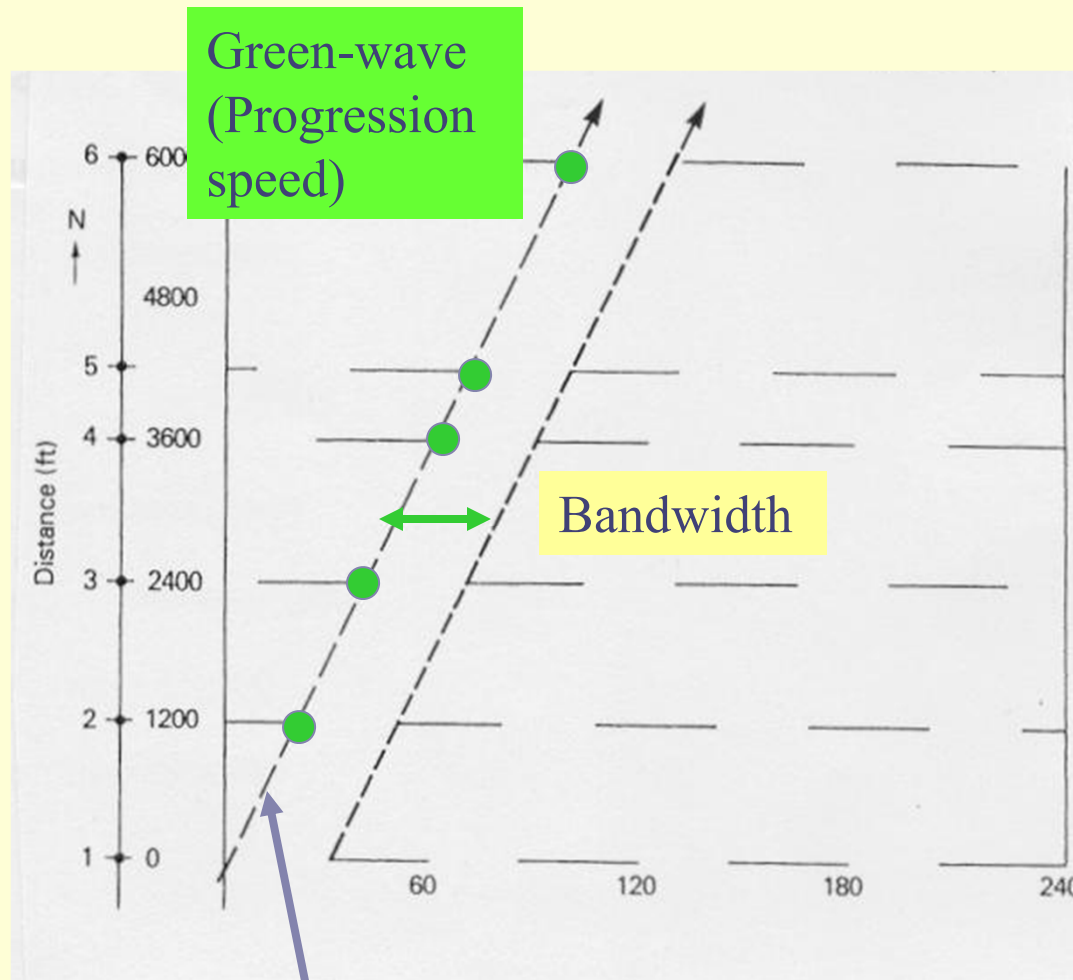
— 800 veh from the side street

24.2 Progression on one-way streets

24.2.1 Determining ideal offsets



What's presented in the T-S diagram



Determining ideal offsets without standing queues at the beginning of green:

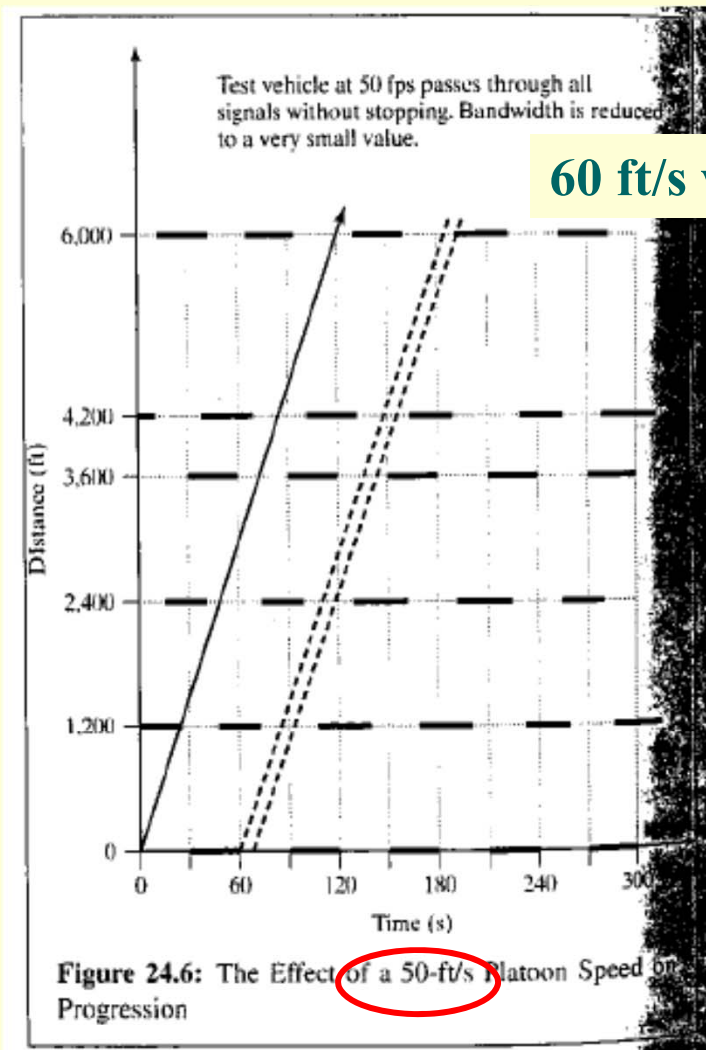
$$Offset = \text{mod}_c [OFFSET]$$

Offsets cannot be greater than the cycle length.

e.g. Offset 72 sec, cycle length 60 sec. Then the offset is 12 sec.

Note that when ideal offsets without queues are used, the speed of the green-wave and trajectory of the first vehicle are the same.

24.2.2 Potential Problems



60 ft/s was used for design

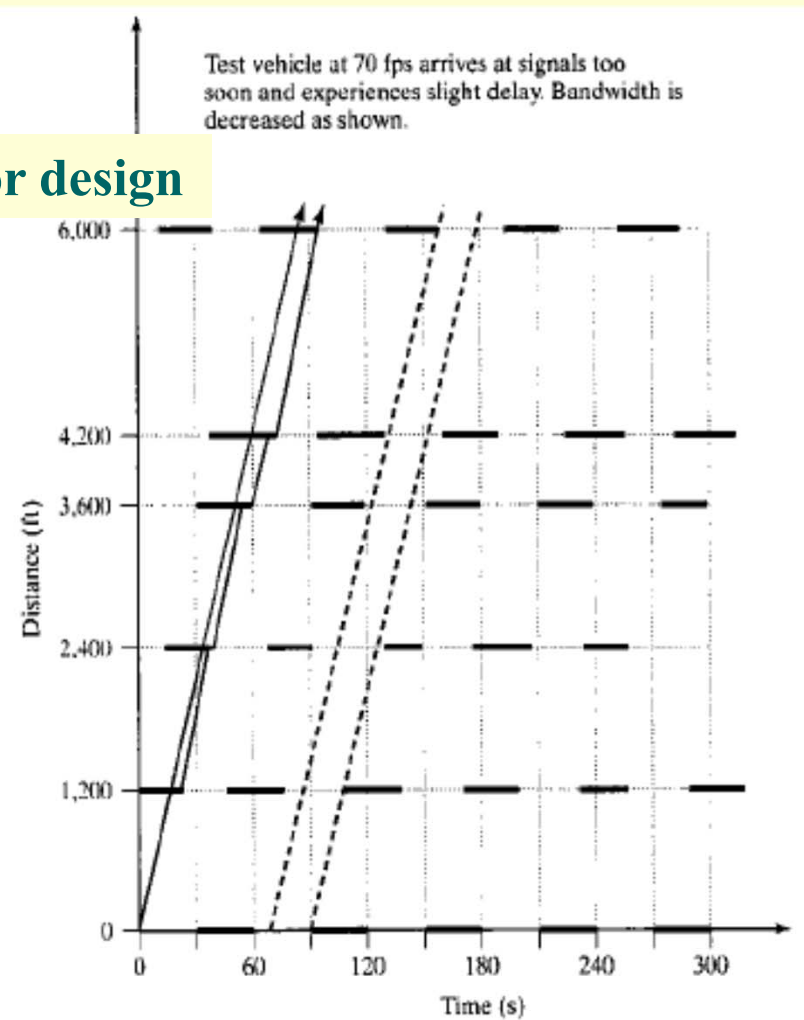


Figure 24.7: The Effect of a 70-ft/s Platoon Speed on Progression

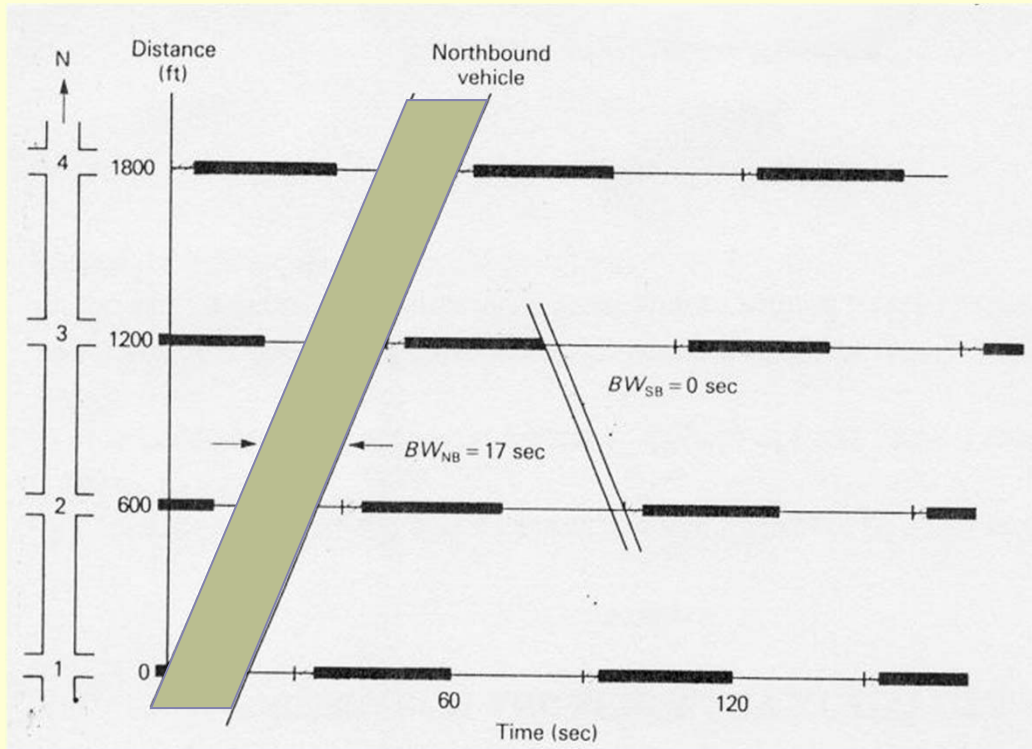
Overestimation of the platoon speed

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Underestimation of the platoon speed

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24.3 Bandwidth concept



■ One weakness → Internal queues are overlooked in the bandwidth approach.

Bandwidth: A “window” of green through which platoons of vehicles can move (without stopping) → This concept is popular because

- The windows of green are easy visual images
- Good solutions can be obtained manually, by trial and error.
- You just need a scaled T-S diagram, a few yarns (speed) and slips of paper (G+R) that shows phase splits. (If it is an arterial system. A network? You need a computer program)



24.3.1 Bandwidth efficiency 24.3.2 Bandwidth capacity

- Efficiency of a bandwidth:

$$Efficiency(\%) = \frac{bandwidth(sec)}{cycle_length(sec)} \times 100$$

An efficiency of 40% to 55% is very good. Note that the bandwidth is limited by the minimum green interval in the direction of interest.

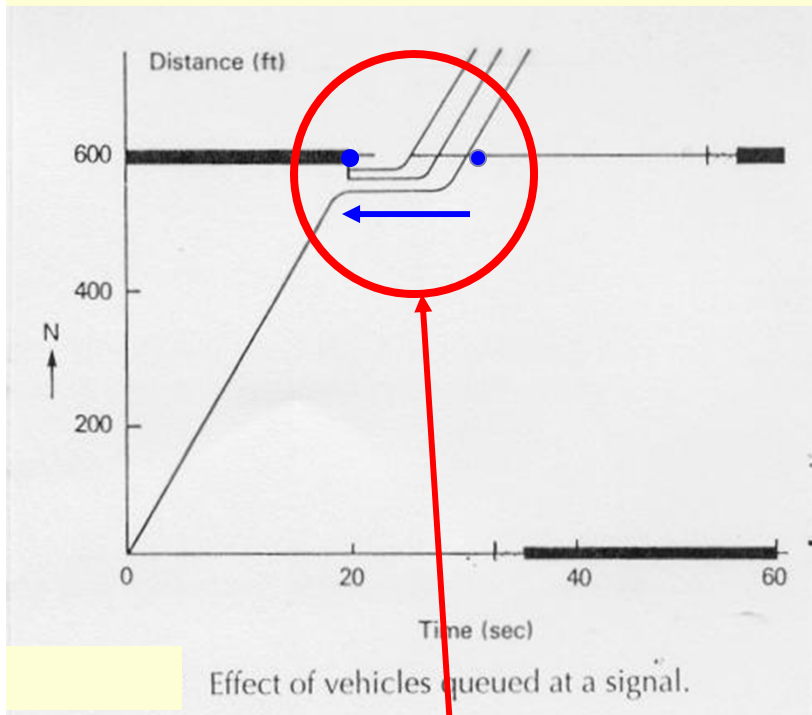
- No. of vehicles that can move through the bandwidth =
Bandwidth (sec) / Headway (sec/veh)

- Nonstop volume if the platoons are organized when they arrive at the entrance of the progressed system (vph):

$$C_{BW} = \frac{BW}{h} \times \frac{3600}{C} \times (No._of_lanes)$$

This equation does not contain any factors usually relevant for signal timing design: lane utilization, pedestrians, turning movement volumes, etc.

24.4 Effect of vehicles queued at signals



If the offset is not adjusted, vehicles from upstream may have to stop joining the queue that has not been cleared.

■ Sometimes there are vehicles stored in the block waiting for a green light. They may be stragglers from the last platoon, vehicles that turned into the block, or vehicles that came out of parking lots or parking spots.

■ Need to adjust offsets to avoid unnecessary stops for the vehicles in the platoon coming from the upstream signal.

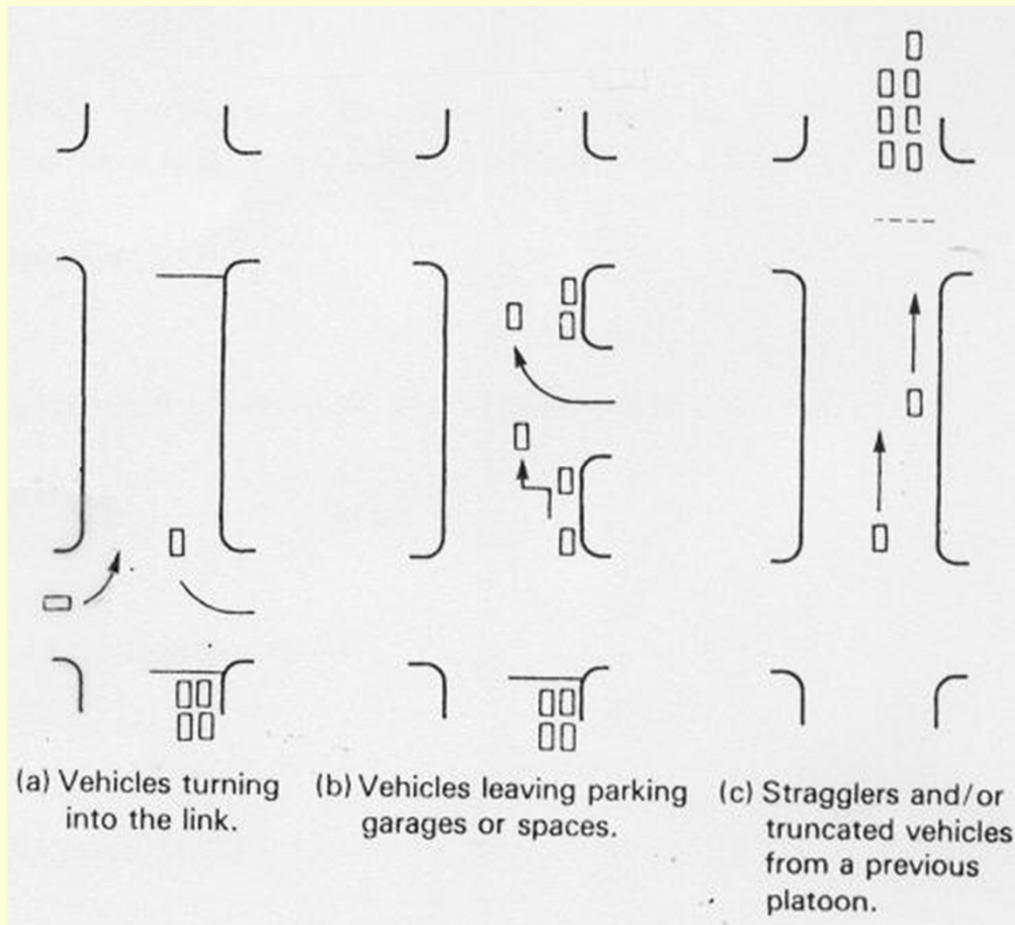
$$t_{ideal} = \frac{L}{S} - (Qh + l_1)$$

Q = No. of vehicles queued per lane, veh

h = discharge headway of queued vehicles, sec/veh

l_1 = starting lost time (add this to only the first downstream intersection assuming lost time is same at all the downstream intersections)

Sources of queued vehicles

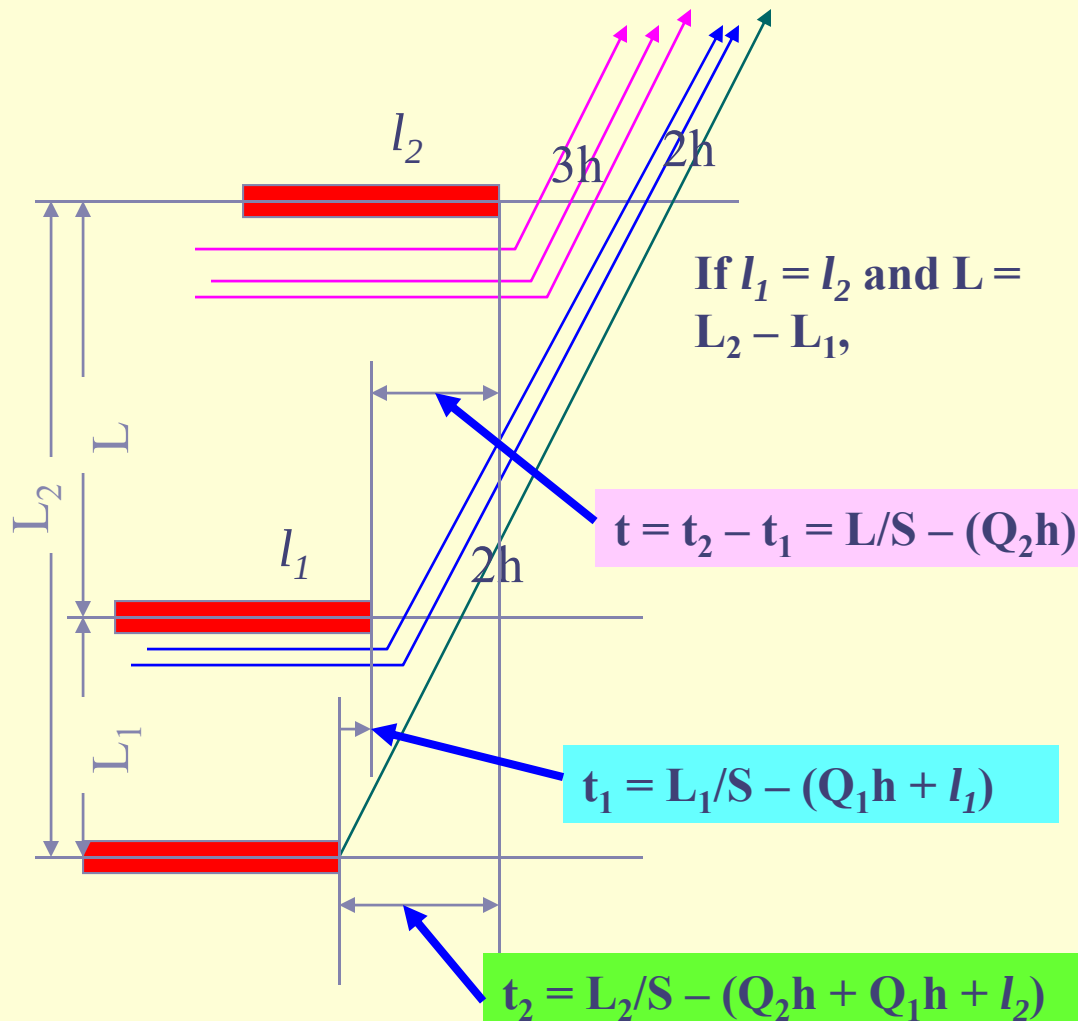


A few sources of queued vehicles

$$t_{ideal} = \frac{L}{S} - (Qh + l_1)$$

- The above equation assumes that we know the queue sizes at the downstream intersections. – Hard to know the size, though.
- But, this is better than not doing any adjustment.
- However, queue formation is dynamic and not static; so, this is only a guess (and hope).

Why don't we need to consider start-up lost time after the first downstream signal?

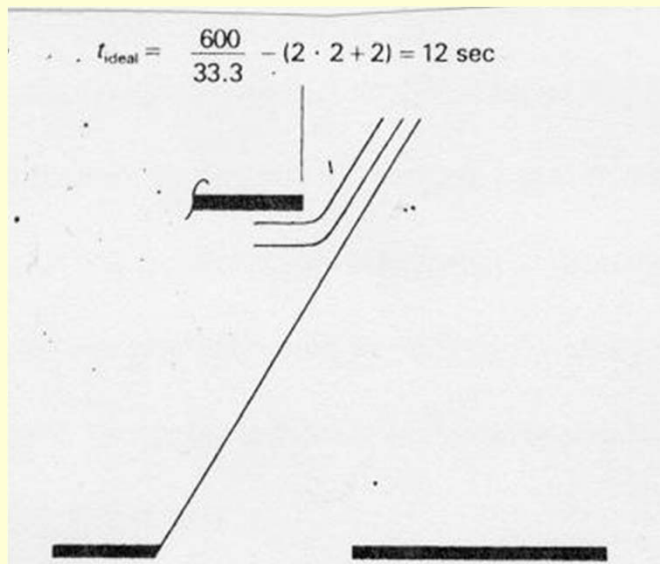


□ Remember we assume that there is no start-up lost time at the first signal (the entry to the system). This assumption is not strictly correct but I'd say it is within the margin of error.

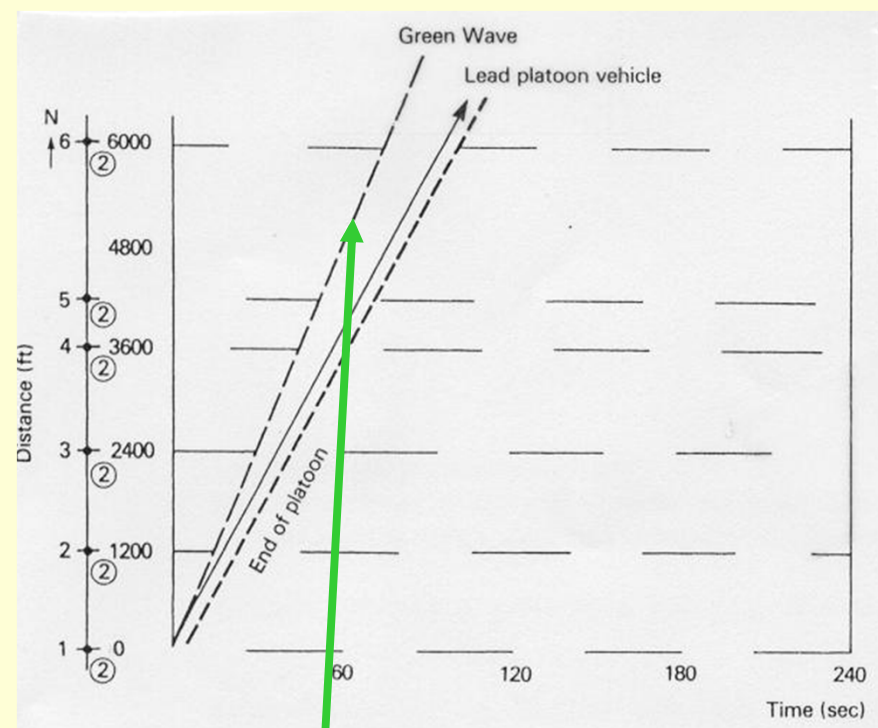
□ We assume that start-up lost times at the downstream signals are the same as the lost time at the second (first one downstream) signal. $l_1 = l_2$

□ The “offset” definition used here is the time difference between the adjacent signals, not from a master controller.

Effect of vehicles queued at signals (Figs 24.10 & 24.11)



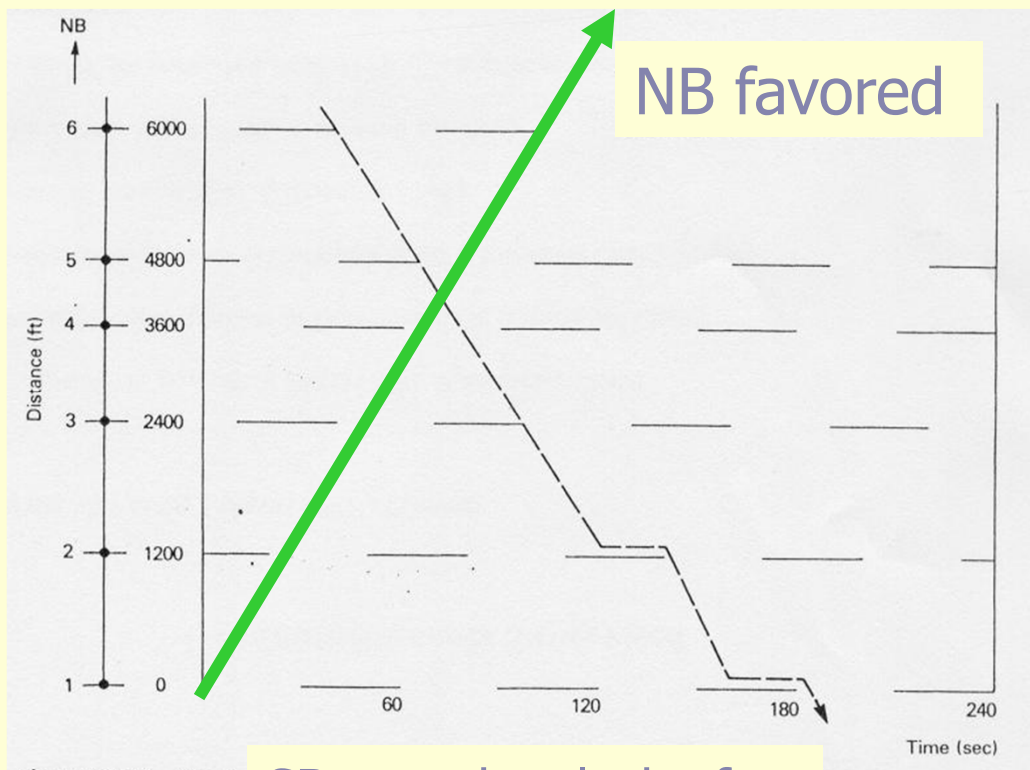
Link	Link offset, sec	Progression speed (green wave) the link, fps
1-2	$(1200/60) - (4+2) = 14$	$1200/14 = 85.7$
2-3	$(1200/60) - (4) = 16$	$1200/16 = 75.0$
3-4	$(1200/60) - (4) = 16$	$1200/16 = 75.0$
4-5	$(600/60) - (4) = 6$	$600/6 = 100.0$
5-6	$(1800/60) - (4) = 26$	$1800/26 = 69.2$
Offset total = 78 sec		



☐ Whenever you adjust for standing queues, the green wave moves faster than the first vehicle of the platoon.

24.5 Signal Progression for Two-Way Streets and Networks

24.5.1 Offsets on a two-way street



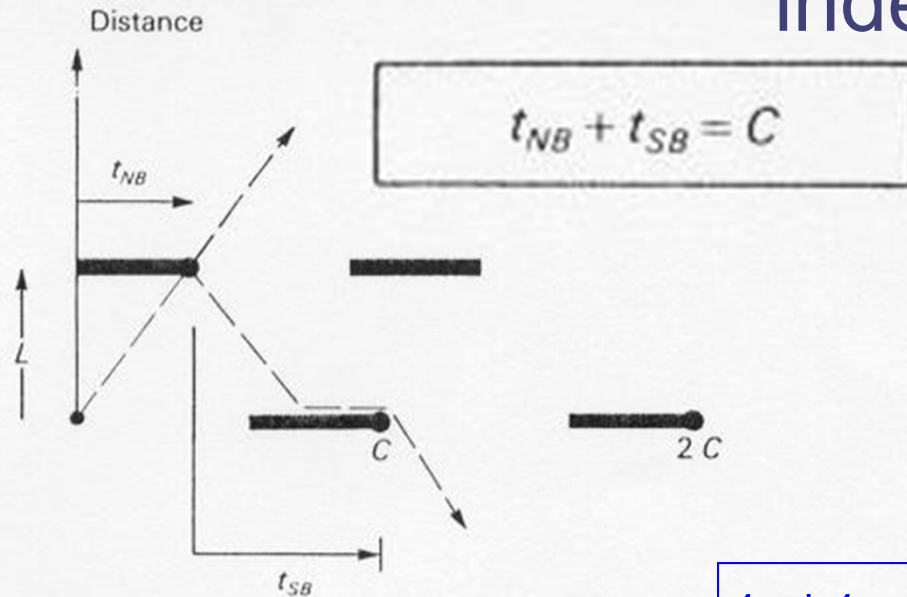
SB gets the slack of the NB preferential treatment!

❖ This sample coordination favors NB. This is allowed if the majority of the vehicles go in one direction, like in a peak period.

❖ In this case, a SB vehicle may stop twice and each time wait about 20 seconds, thus 40 seconds of delay.

Offsets are interrelated!

Offsets on a two-way street are not independent



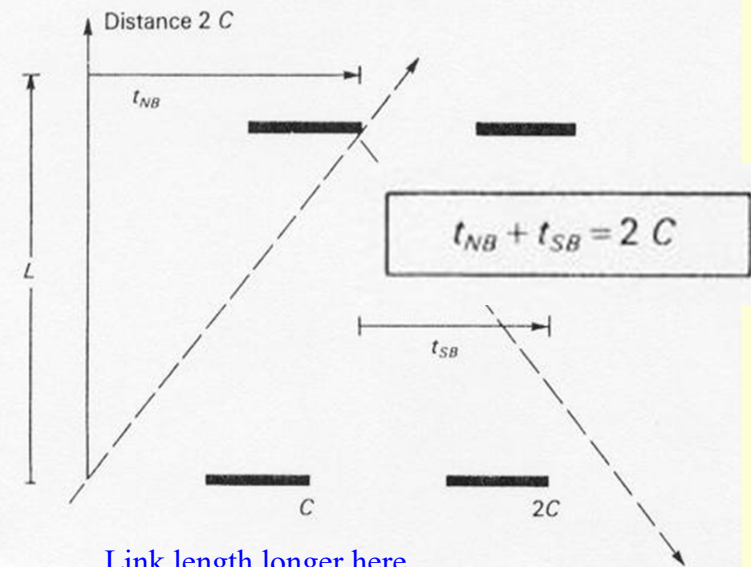
(a) Offsets add to one cycle length

C is zero for a "simultaneous green" system.

$$t_{NB} + t_{SB} = 0$$

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These figures show both offsets and actual travel times. Actual travel times may be equal to, shorter, or longer than offsets. We try to minimize the difference between the offsets and actual travel times

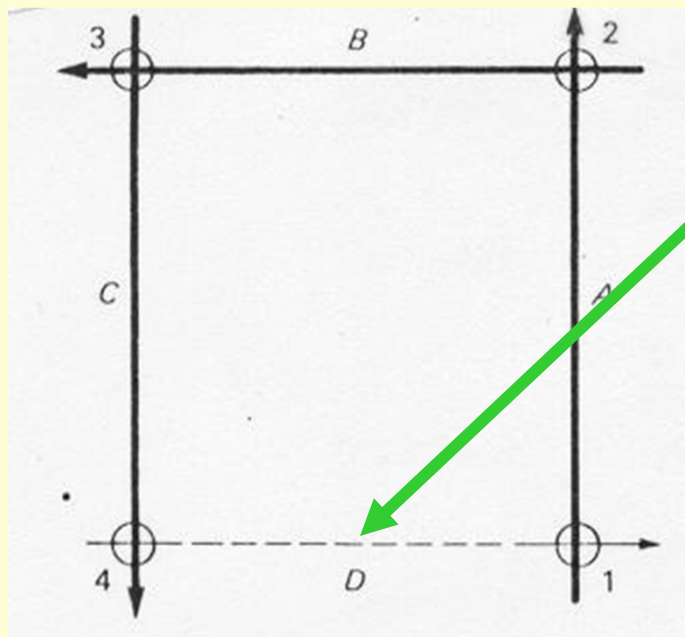


Link length longer here

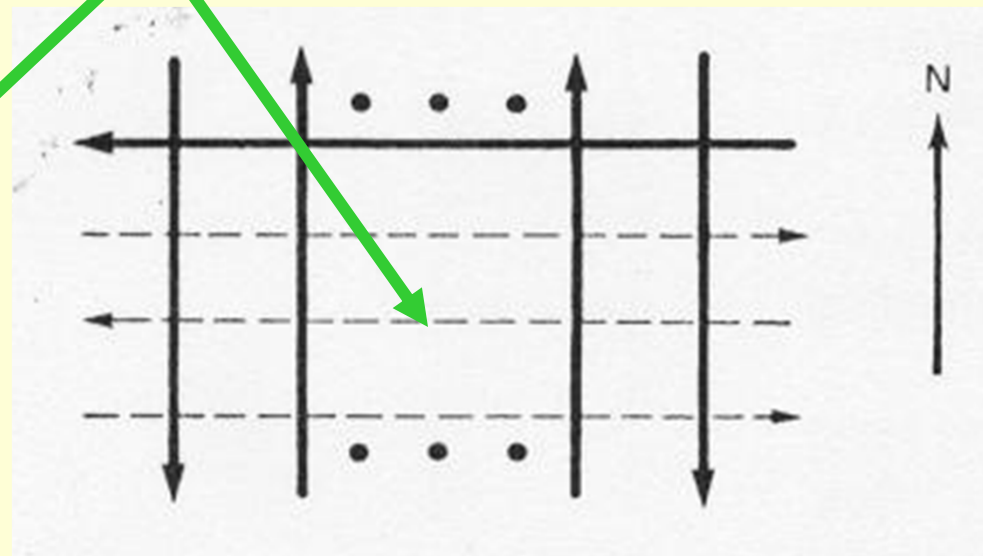
(b) Offsets add to two cycle lengths

24.5.2 Network closure (one-way network example)

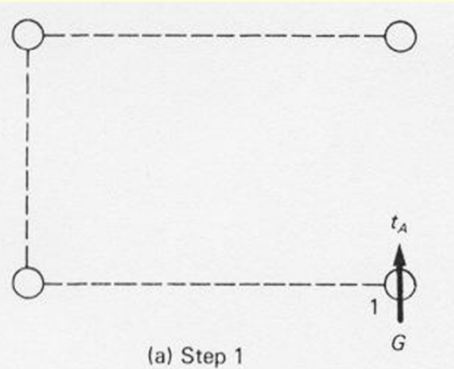
□ An open tree of one-way links can be completely independently set. In this case, it is the closing or “closure” of the open tree which presents constraints on some of the links.



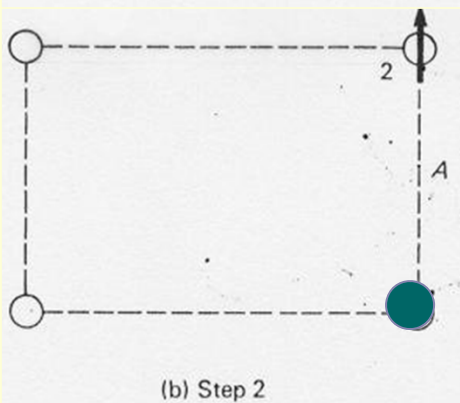
“Closure” of open trees.



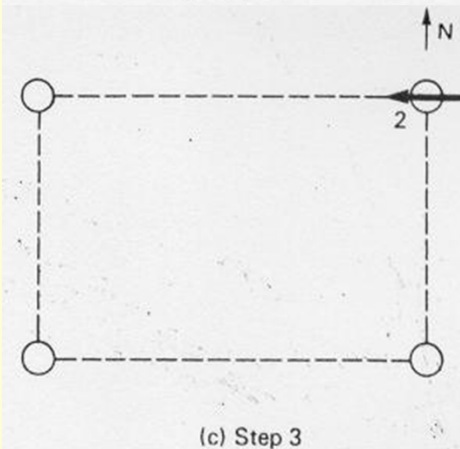
Offset determination in a grid (cont): “closure” rule



Step 1. Begin at Intersection 1 and consider the green initiation to be time $t = 0$.



Step 2. Move to Intersection 2, noting the the link offset in Link A specifies the time of green initiation at this intersection, relative to its upstream neighbor ●. It takes t_A sec.

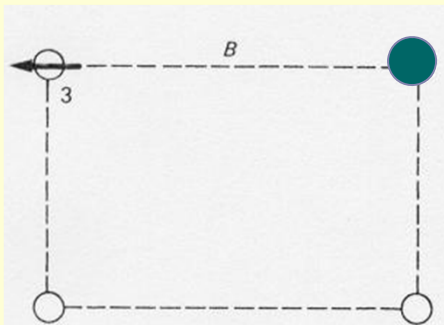


Step 3. Recognizing we must ask, “When do the WB vehicles get released at Intersection 2?”, note that this occurs after the NS green is finished. Thus we are now at

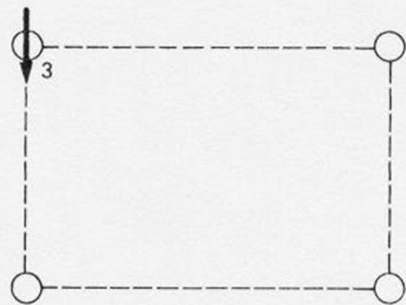
$$t = 0 + t_A + g_{NS,2}$$

and facing west at Intersection 2.

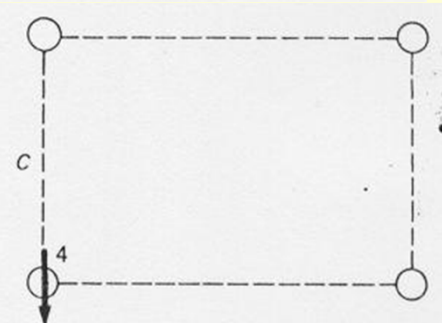
Offset determination in a grid (cont): “closure” rule



(d) Step 4



(e) Step 5



(f) Step 6

Step 4. Move to Intersection 3, noting similarly to Step 2 that the link offset in Link B specifies the time of green initiation at this intersection, relative to its upstream neighbor ●. It takes t_B .

Step 5. Asking “when do the southbound vehicles get released at Intersection 3?” note that this occurs after the EW green is finished. Thus we are now at

$$t = 0 + t_A + g_{NS,2} + t_B + g_{EW,3}$$

and facing south at Intersection 3.

Step 6. Moving to Intersection 4, it is t_C which is added.

$$t = 0 + t_A + g_{NS,2} + t_B + g_{EW,3} + t_C$$

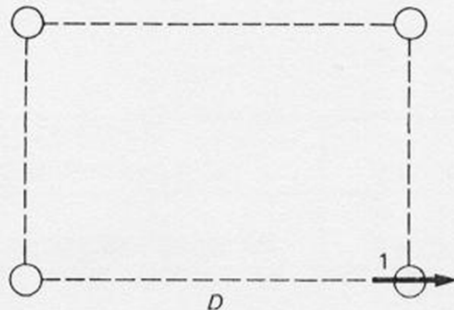
Offset determination in a grid (cont): “closure” rule



(g) Step 7

Step 7. Turning at Intersection 4, it is the NS green which is relevant and we are facing east at Intersection 4.

$$t = 0 + t_A + g_{NS,2} + t_A + g_{EW,3} + t_C + g_{NS,4}$$



(h) Step 8

Step 8. Moving to Intersection 1, it is t_D which is relevant.

$$t = 0 + t_A + g_{NS,2} + t_A + g_{EW,3} + t_C + g_{NS,4} + t_D$$



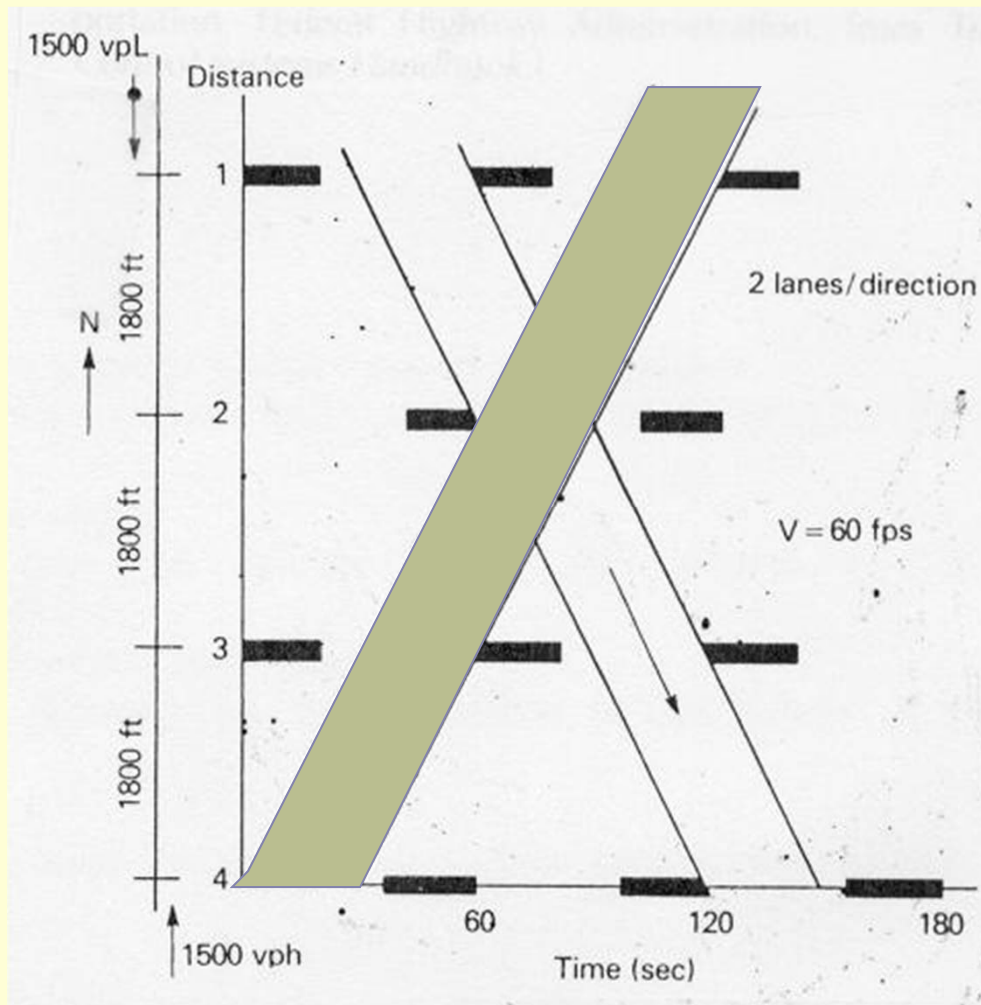
(i) Step 9

Step 9. Turning at Intersection 1, it is the EW green which is relevant.

$$t = nC = 0 + t_A + g_{NS,2} + t_A + g_{EW,3} \\ + t_C + g_{NS,4} + t_D + g_{EW,1}$$

(Include Y+AR in the g value above.)

24.5.3 Finding compromise solutions



Given:

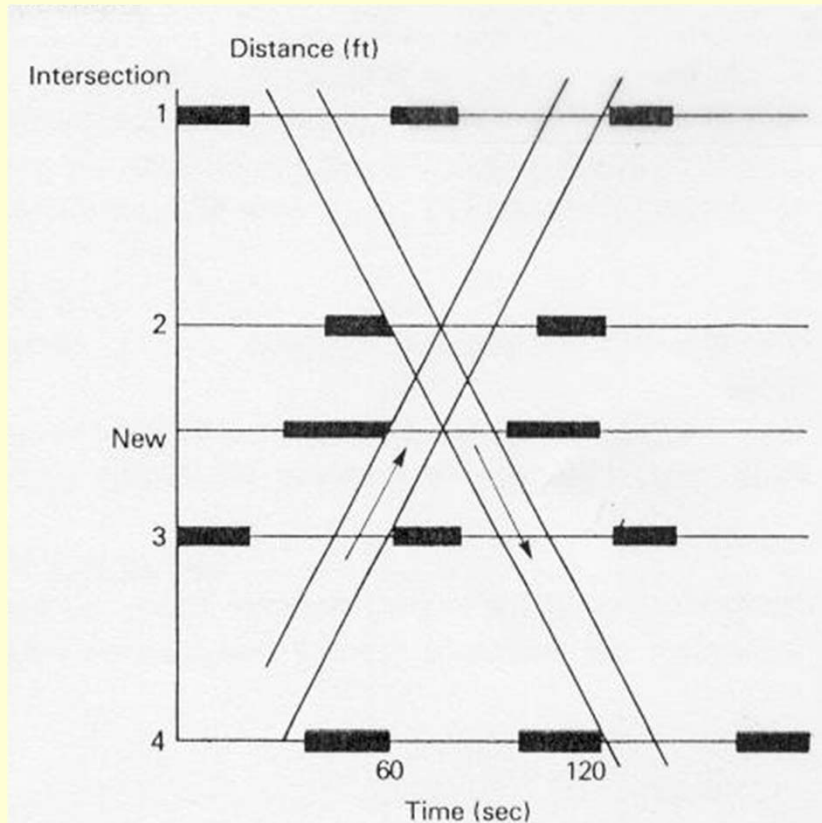
- ☐ Both directions have the equal weight
- ☐ Have about 25 seconds of greenband

Requirements:

- ☐ A new traffic light will be needed halfway between nodes 2 and 3
- ☐ Provide the same bandwidth to both directions

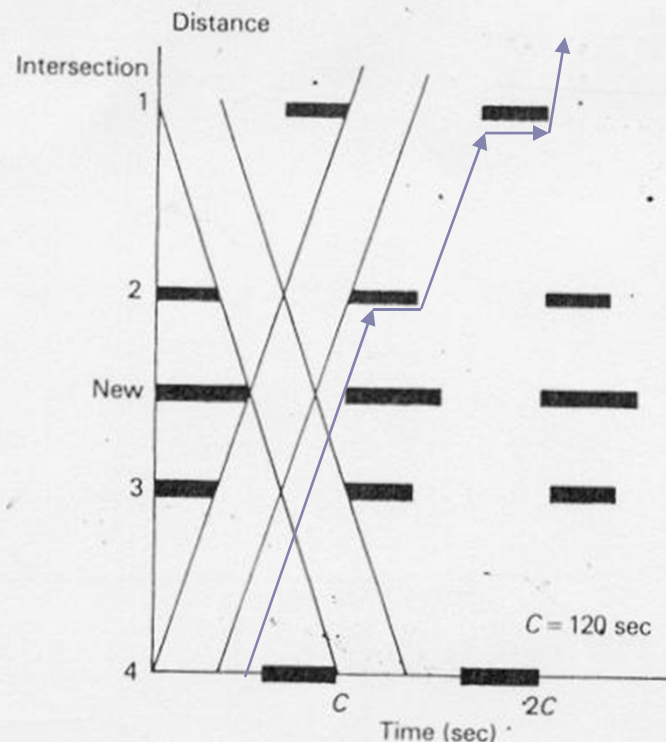
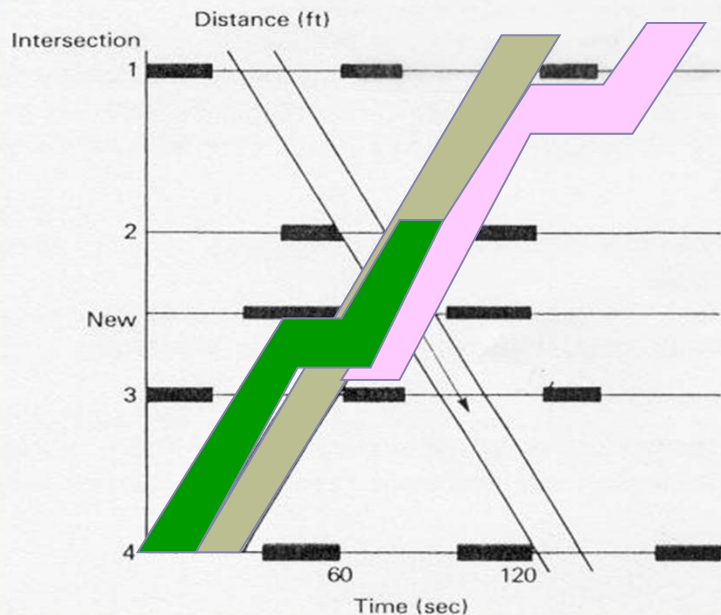
The bandwidth is about 25 seconds.

One solution, same cycle length



In this case, cycle length remains the same and offsets were adjusted. Note the narrower band widths (about 15 seconds). → May not be able to meet the demand.

- Prepare a strip of paper indicating signal splits for each intersection
- Place a guideline (a yarn or thread) to indicate the speed of the platoons by the slope of the guidelines
- Slide the strips relative to each other until an improved offset pattern is identified
- Continue move the offsets around until a more satisfactory timing plan develops.
- A change in cycle length may even be required (although side streets may wait longer and suffer more delays)



Problems with changing bandwidths

- Part of the original bandwidth may be chopped off
- Queues may be formed due to the narrower bandwidth (which will disturb the platoon in the next cycle)
- Check if changing cycle length can provide a wider bandwidth (if C gets longer, more vehicles will be in the platoon, hence the band must be wider)

Now $C = 120$ sec and the bandwidth is about 40 seconds

24.6 Common Types of Progression

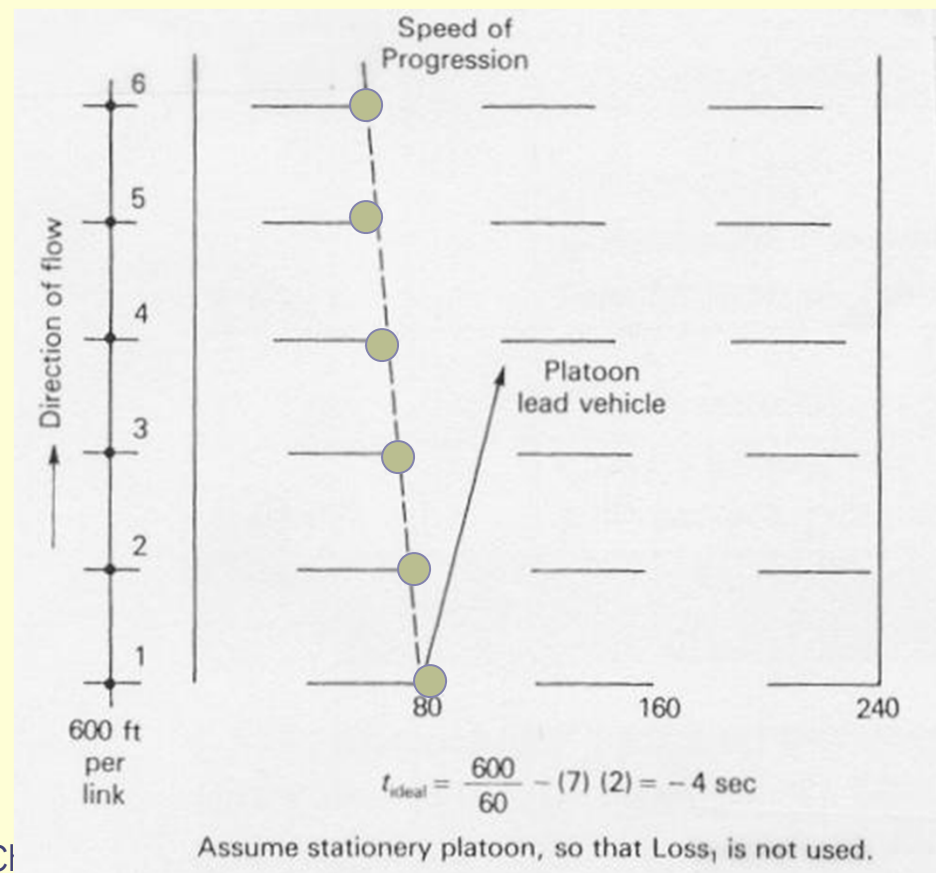
- Simple progression
- Forward progression
- Flexible progression (progression coordination changes during the day to meet the peak demand direction)
- Reverse progression (this will result when queue adjustment to the ideal offset is large → See the figure on the right)

$$t_{ideal} = \frac{L}{S} - (Qh + l_1)$$

- Simultaneous progression

Reverse progression

- Downstream greens will turn on earlier than upstream greens (too much offset adjustment)



24.6.2 Alternating progression

● Alternate progression works when...

For certain block lengths with 50:50 splits and uniform block lengths, it is possible to select a feasible cycle length that

$$\frac{C}{2} = \frac{L}{S}$$
$$\frac{L}{S} + \frac{L}{S} = \frac{2L}{S} = C$$

The efficiency is 50%,
but with zero internal
queues.

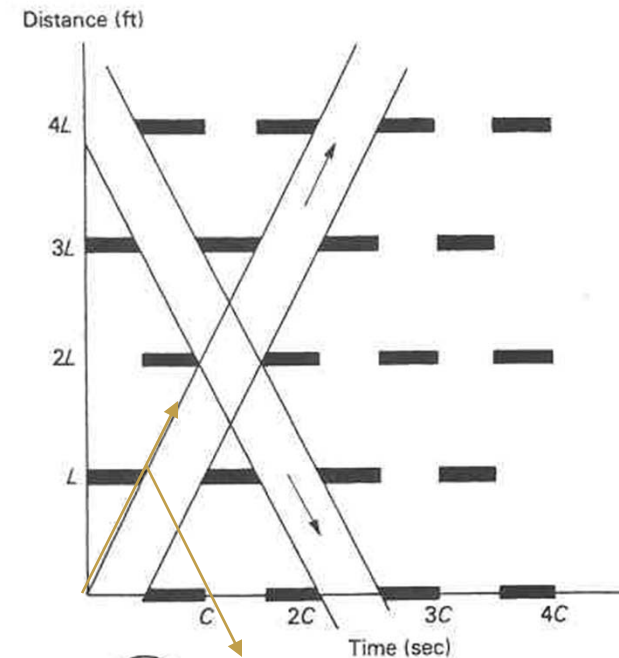


Figure 22-23 Alternate system illustrated.

24.6.3 The double-alternating progression

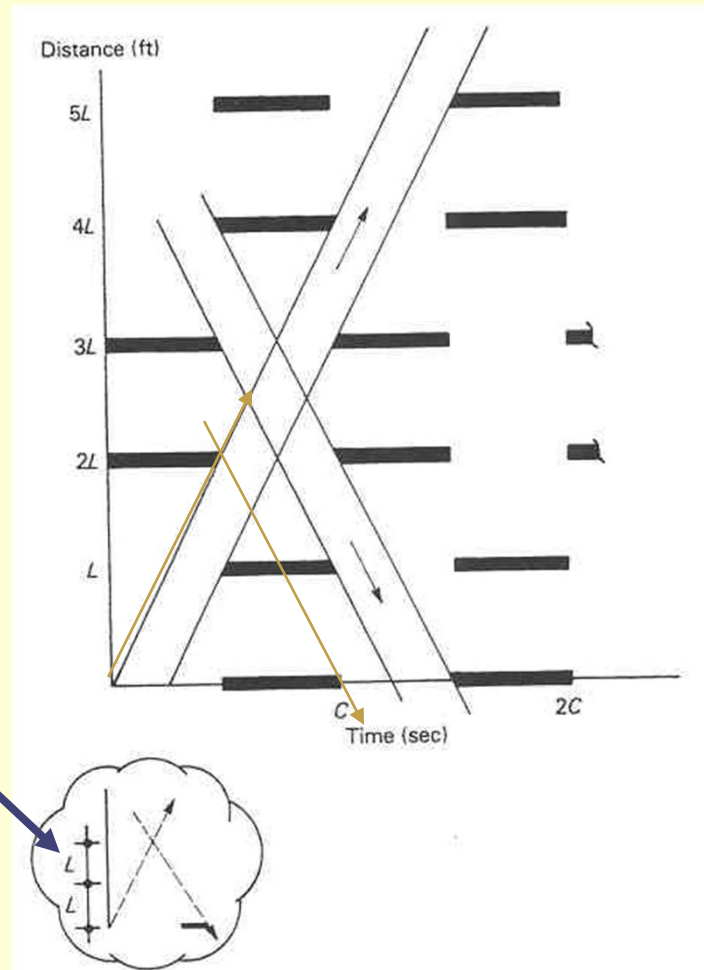
● Double alternate progression works when...

For certain block lengths with 50:50 splits and uniform block lengths, it is possible to select a feasible cycle length that

$$\frac{C}{4} = \frac{L}{S}$$

$$\frac{2L}{S} + \frac{2L}{S} = \frac{4L}{S} = C$$

The efficiency is 25%,
but with zero internal
queues.



Chapter 2 Figure 22-24 Double alternate system illustrated.

24.6.4 The simultaneous progression

● Simultaneous progression works when...

For very closely spaced signals, or for rather high speeds, it may be best to have all the signals turn green at the same time.

The efficiency of a simultaneous system depends on the number of signals involved.

$$\left[\frac{1}{2} - \frac{(N-1)L}{(S)(C)} \right] 100\%$$

For N=4 (4 signals), L=400ft, C=80 sec, S=45fps, the efficiency is 16.7%. A very narrow band → So drivers tend to speed to clear as many signals as they can.

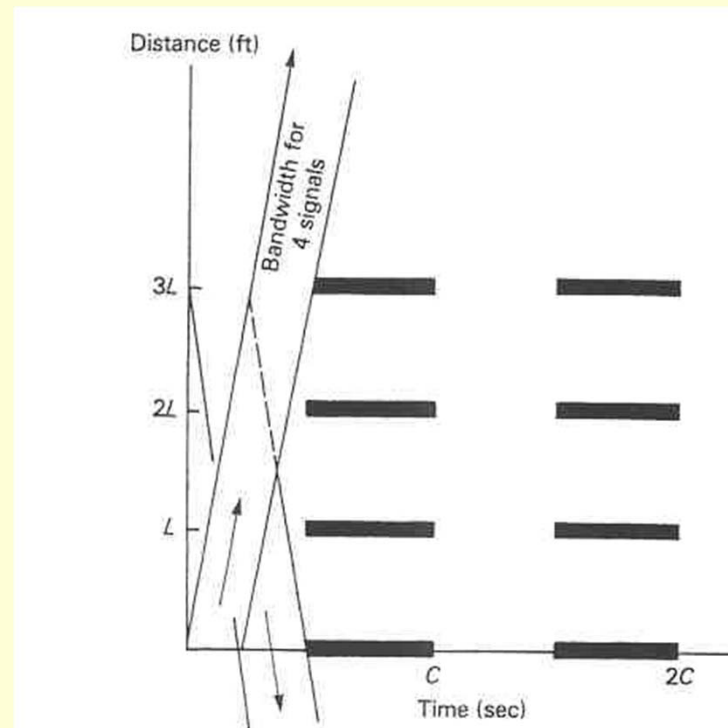


Figure 22-25 Simultaneous system illustrated.



24.7 Coordination of Signals for Oversaturated Networks (not covered in fall 2009)

Progression may be a moot question.

But before getting weary, look at the existing signal timings carefully and improve them by:

- Shorter cycle length
- Proper offsets (including queue clearance)
- Proper splits

Example: When I moved to Provo in 1997, signals on State Street in Orem were not coordinated. Around 2000 they were coordinated.

Oversaturated traffic (cont)

- Metering plans → This is an interesting concept.
 - Internal, external (combined with congestion pricing), release metering

