Signal Coordination for Arterials and Networks

CIVL 4162/6162

Learning Objectives

- Define progression of signalized intersections
- Quantify offset, bandwidth, bandwidth capacity
- Compute progression of one-way streets, two-way streets, and networks
- Estimate progression by different types

Progression: Why Needed

- Where signals are close enough together
- Vehicles arrive in platoons
- It is necessary to coordinate their times so that vehicles may move efficiently through set of signals

Signal Spacing and Progression

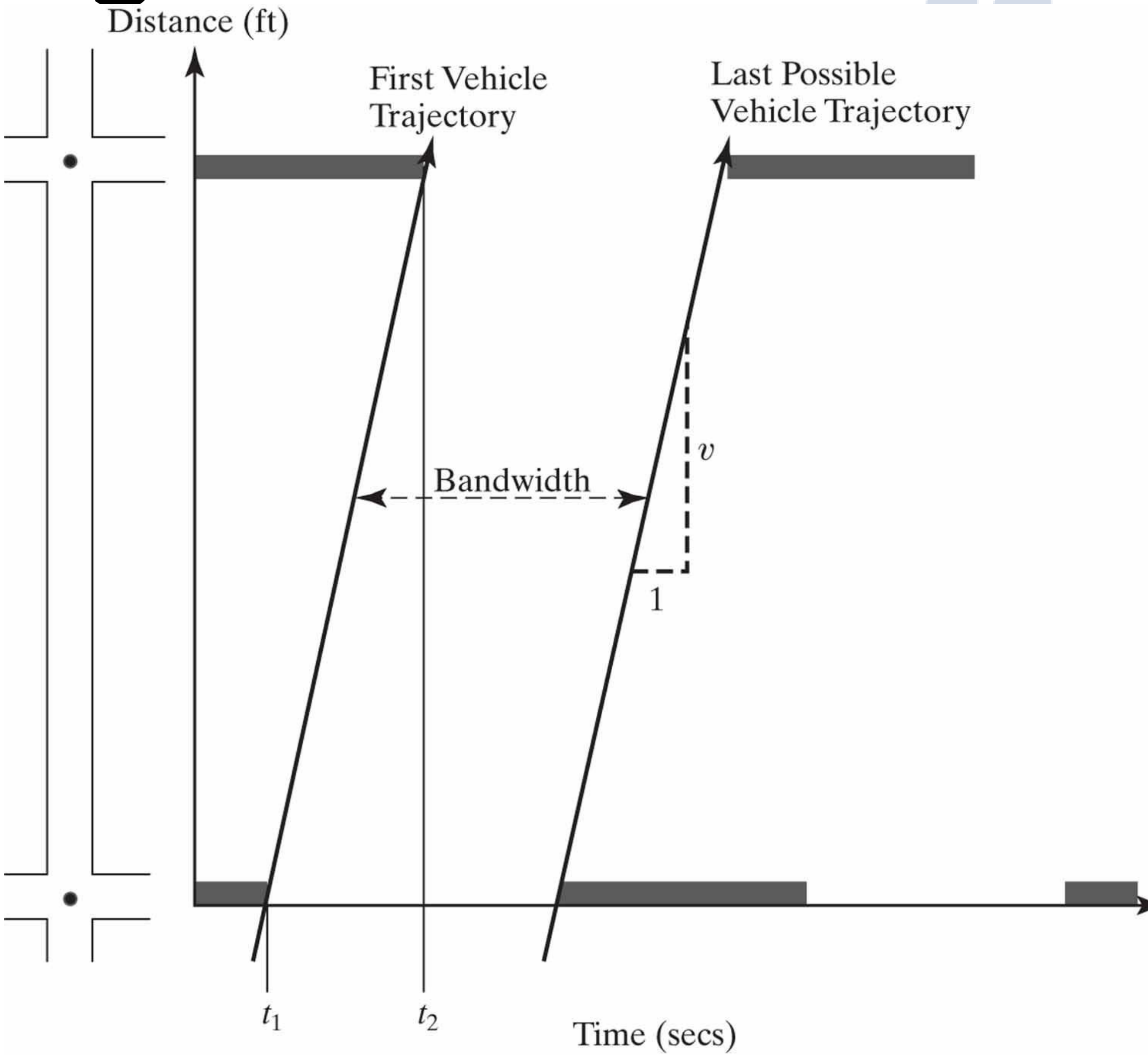
- In some cases signals are so closely spaced that they should be considered as one signal
- In other cases, signals are so far apart that they may be considered as isolated
- Common practice is to coordinate signals less than a mile apart on major streets and highways

Key Requirement

- All intersections in system are to have the *same cycle length or multiple of minimum cycle length*
  - long enough to provide sufficient capacity at the busiest intersection
- System cycle length is determined through a series of steps
  - determine the minimum (optimum) cycle length at each intersection
    - as if they are isolated signals

Time Space Diagram

- Path a vehicles takes as time passes
- $t=t_1$
  - first signal turns green
- $t=t_2$
  - vehicle reaches second signal
- *Offset:* Difference between green initiation times (t_2-t_1)



Offset

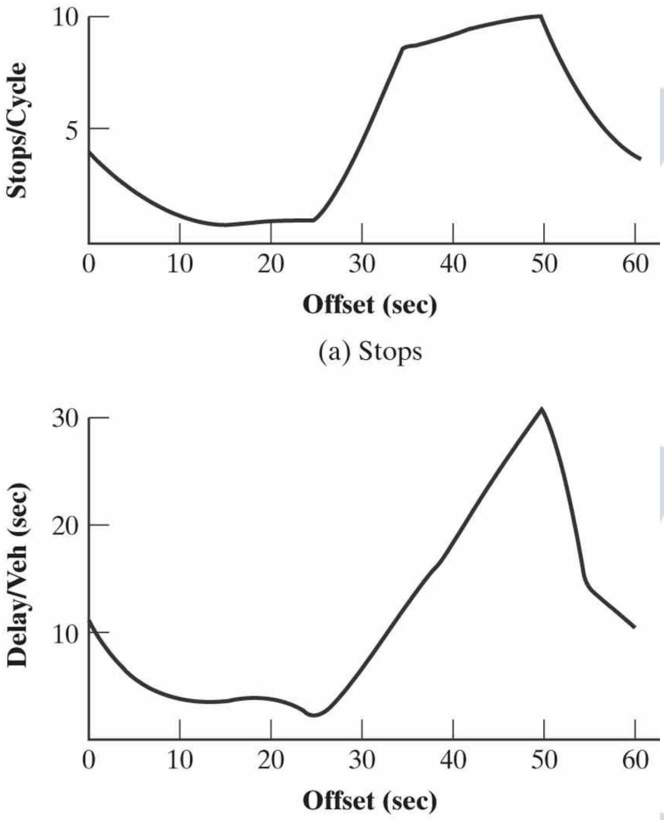
- Ideal offset is defined as time needed for the first vehicle of the platoon just arrives at the downstream signal when its green

$$t_{ideal} = \frac{L}{S}$$

  - t_{ideal}: ideal offset, sec
  - L: Distance between signalized intersections, ft
  - S: Vehicle speed, ft/sec
- Offset is a positive number between zero and cycle length

Offset is critical

- Ideal offset 25 sec
- See the effect of poor offset
- An offset of (25+10=35 sec)
  - Causes more harm than
  - an offset of (25-10=15 sec)



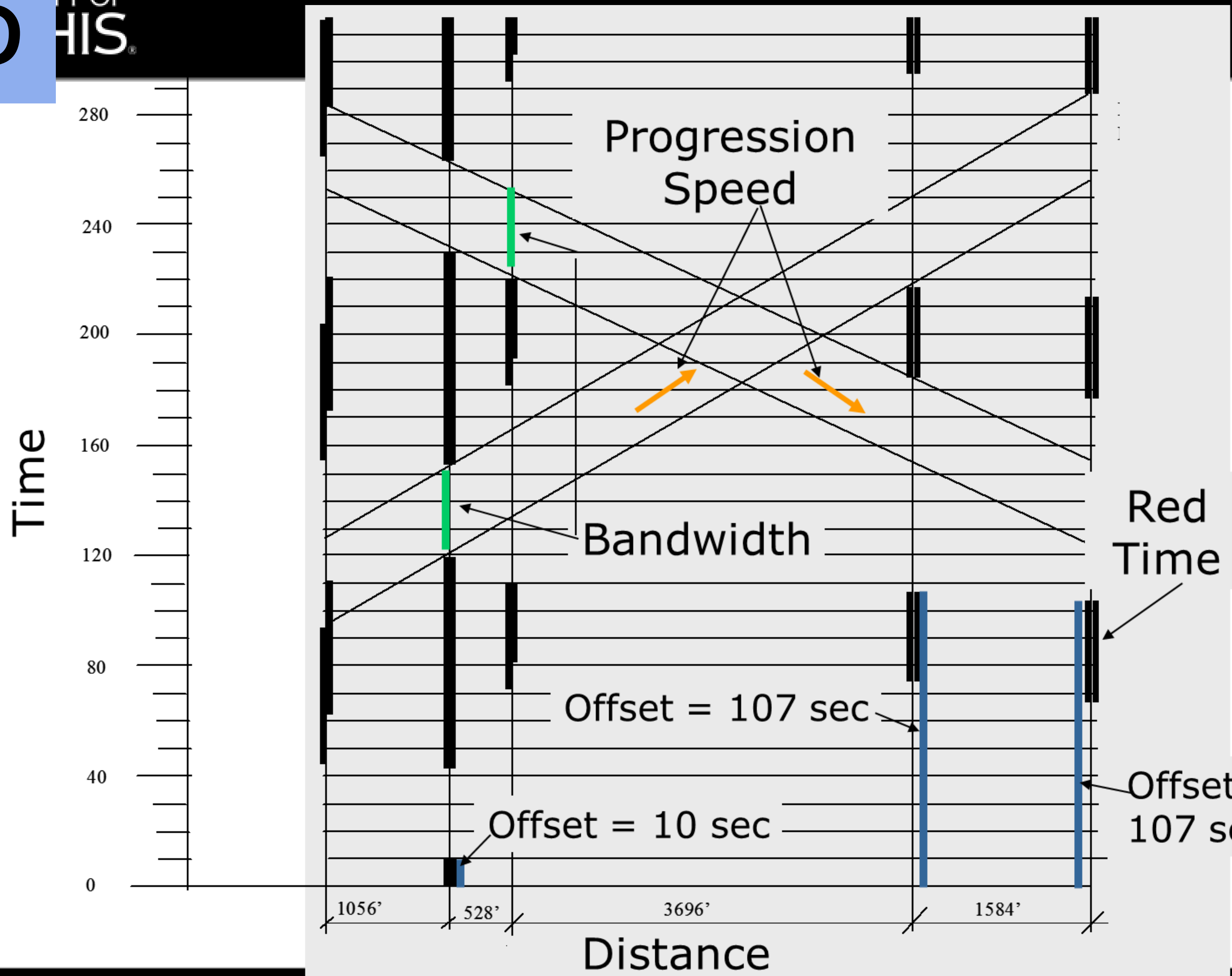
(a) Stops

(b) Delay

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

Bandwidth

- Defined as the amount of green time that can be used by a continuous moving platoon of vehicles through a series of intersections
- In the example, slide#5,
  - The green time at both intersections are same
  - The ideal offset is illustrated
  - There are only two intersections


Time
280
240
200
160
120
80
40
0
Progression
Speed
Bandwidth
Red
Time
Offset = 107 sec
Offset = 10 sec
1056'
528'
3696'
1584'
Distance

Signal Progression of One-Way St.

Assumptions: (1) Desired platoon speed: 60ft/sec; (2) Cycle length = 60sec
(3) Effective green time = 30 sec

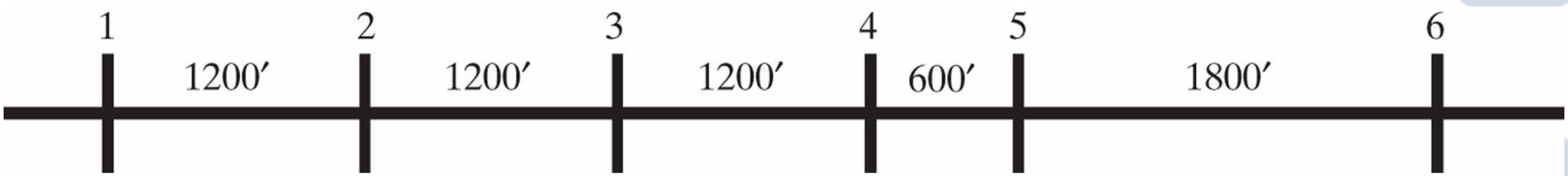
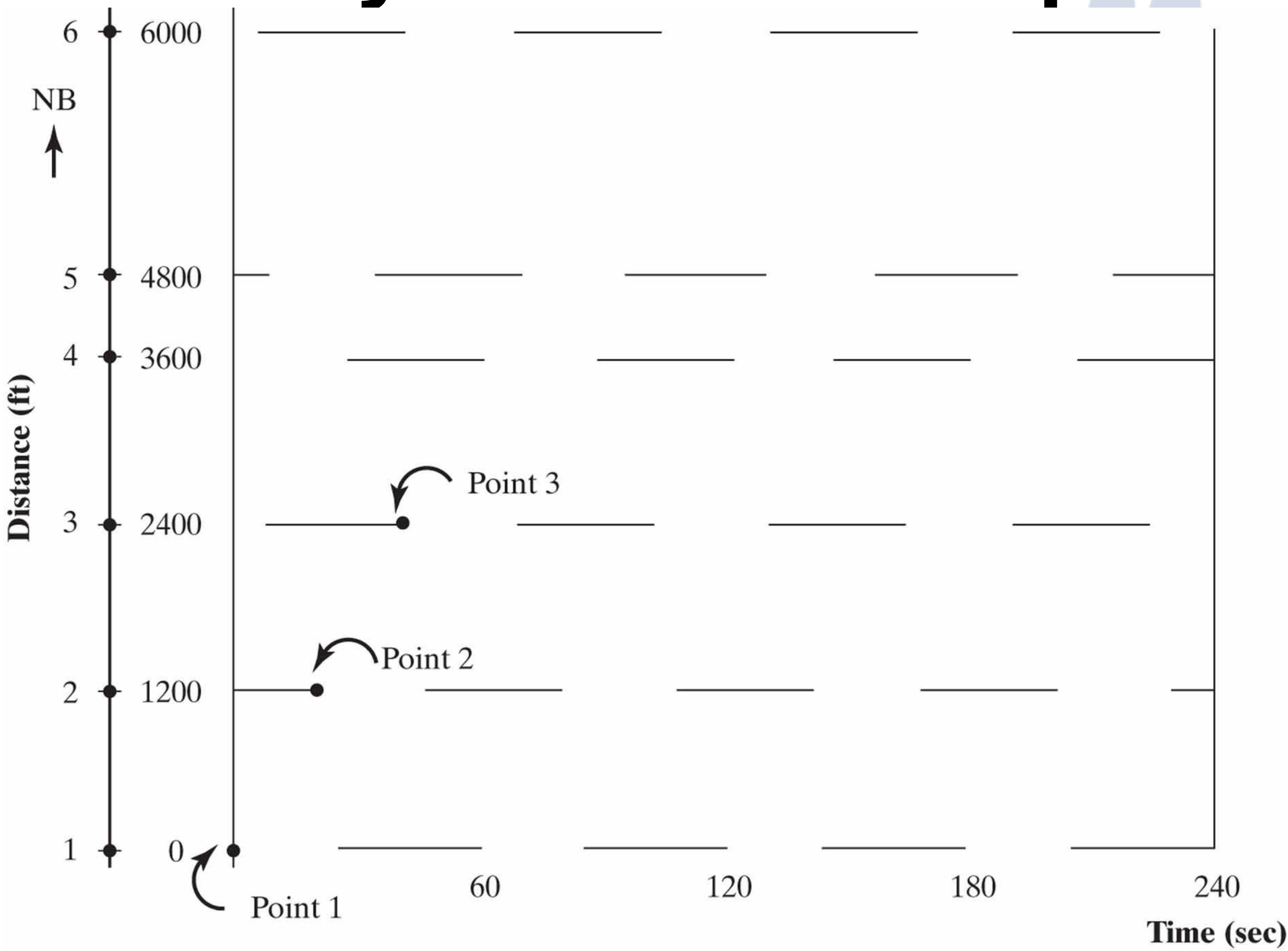


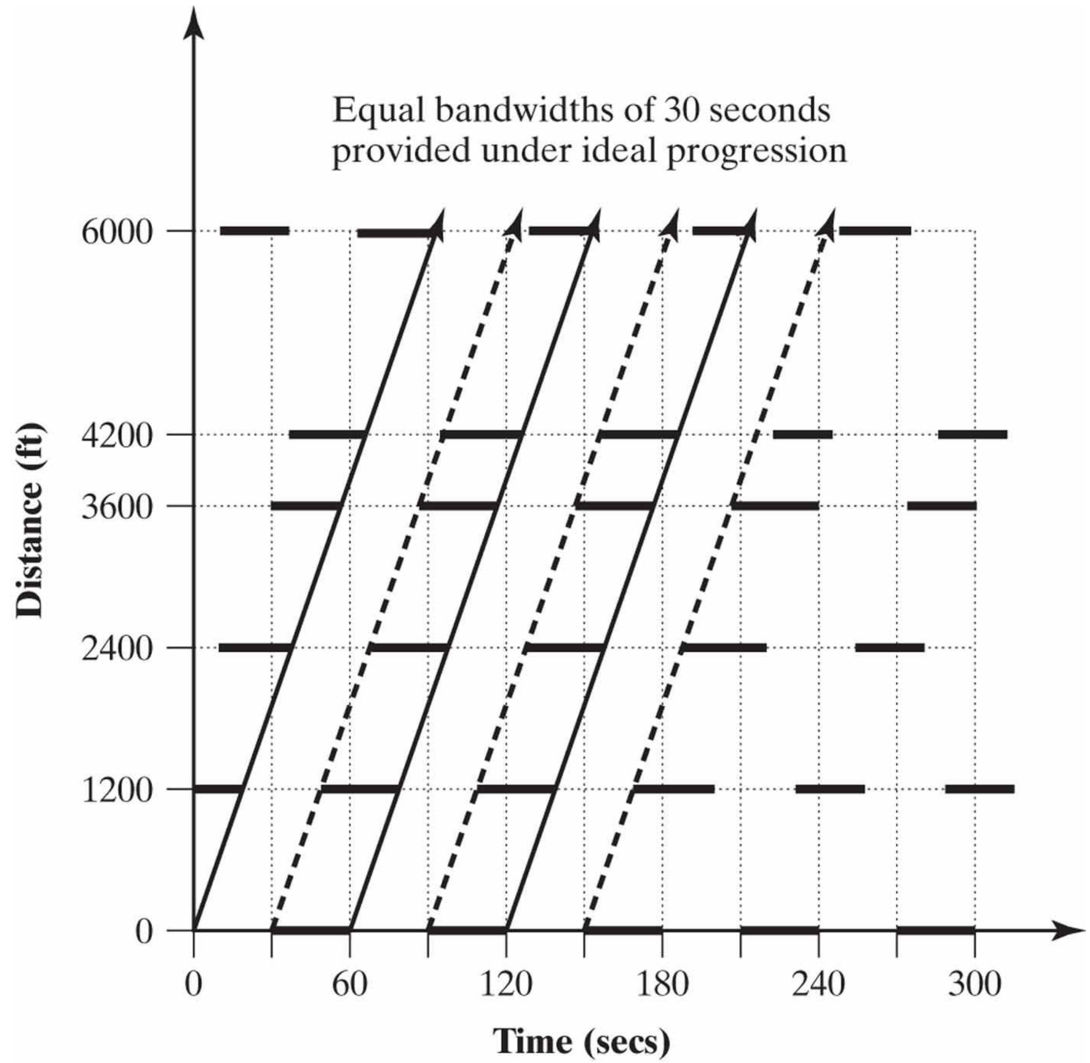
Table 26.1: Ideal Offsets for Case Study

Signal	Relative to Signal	Ideal Offset
6	5	1,800/60 = 30 s
5	4	600/60 = 10 s
4	3	1,200/60 = 20 s
3	2	1,200/60 = 20 s
2	1	1,200/60 = 20 s

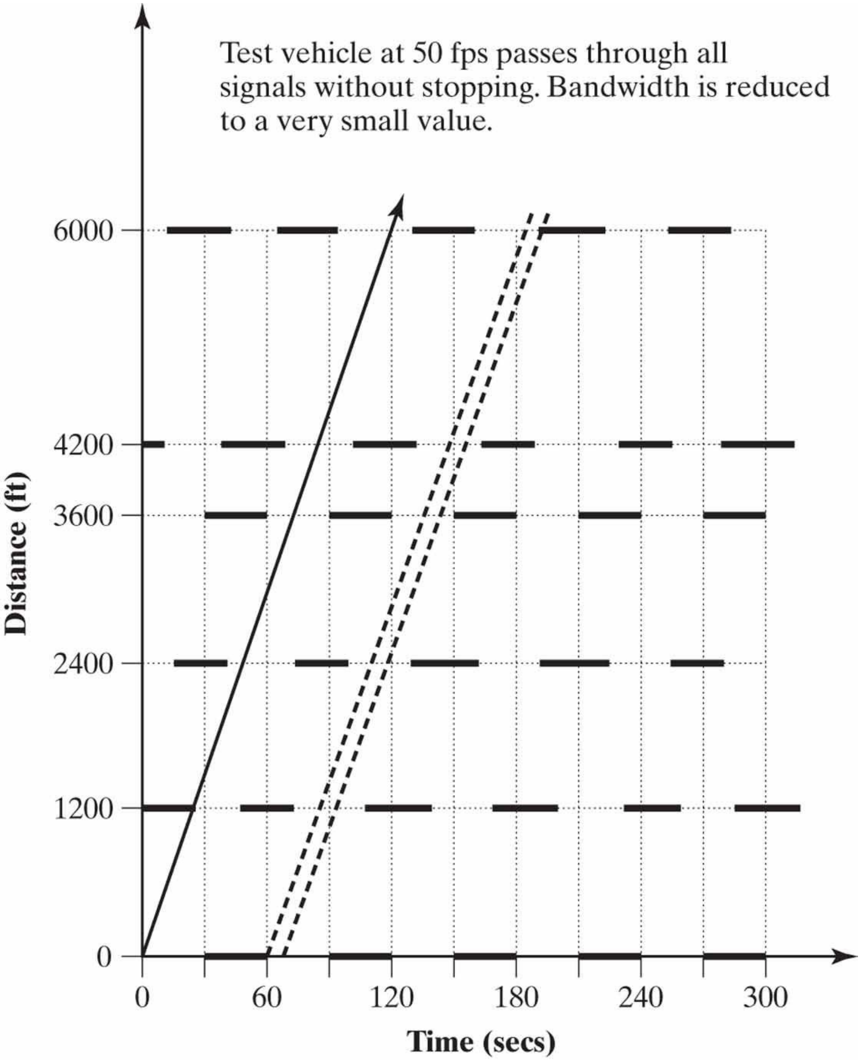
TSD for One-way Street Example



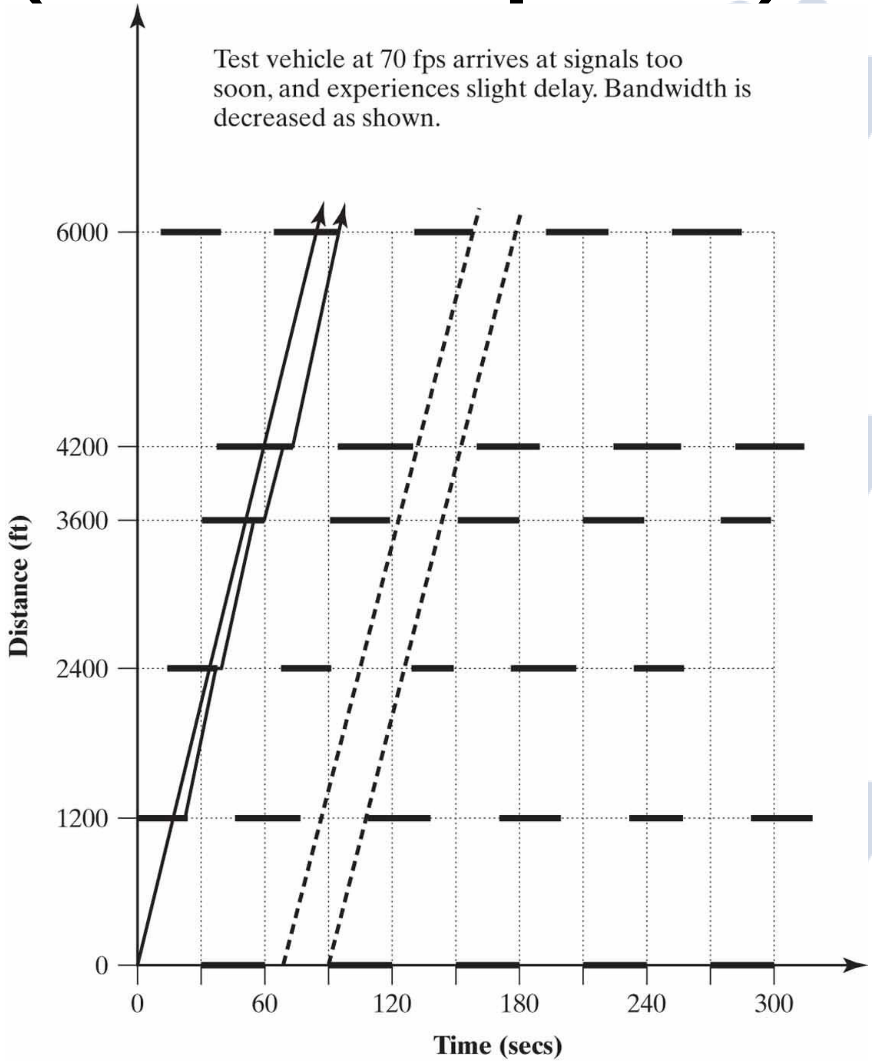
Bandwidth


Equal bandwidths of 30 seconds provided under ideal progression
Distance (ft)
6000
4200
3600
2400
1200
0
0
60
120
180
240
300
Time (secs)

Potential Problems (Vehicle Speed)



Small Time Window



Relatively Larger Time Window

Bandwidth Concepts

- Definition again: Defined as the time difference between the first vehicle that pass through the entire system without stopping and the last vehicle that can pass through without stopping, measured in seconds.

Bandwidth Efficiency

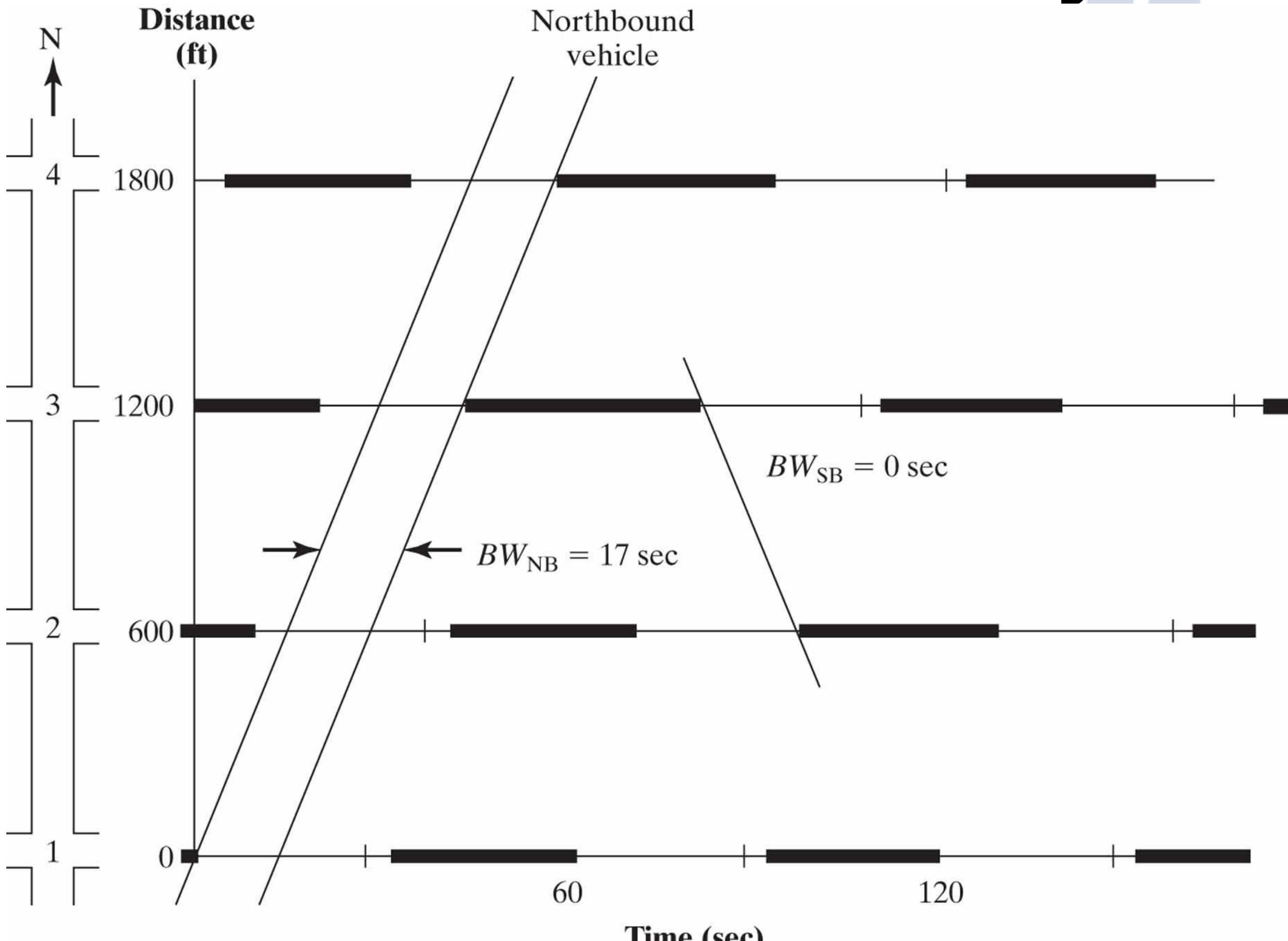
- The efficiency of bandwidth is defined as the ratio of the bandwidth to the cycle length, expressed as percentage

$$EFF_{BW} = \left(\frac{BW}{C}\right) * 100\%$$

  - EFF_{BW}: Bandwidth efficiency (%)
  - BW: Bandwidth, sec
  - C: Cycle length, sec
- Bandwidth efficiency of 40% to 55% is considered good

Example: Bandwidth Efficiency

- NB: (17/60)*100 = 28.4%
- SB= 0



Bandwidth Capacity

- Defined as the number of vehicles that can pass through the system without stopping in one hour
- In the previous example:
  - Consider a saturation headway of 2.0 sec/veh
  - Vehicles can pass per cycle: 17/2= 8.5 veh/cycle
  - Thus NB direction can handle
    - [8.5 (veh/cycle)]* [1/60 cycle/sec]*[3600 sec/hr]
    - =510 veh/hr

Bandwidth Capacity (2)

- If the per lane demand volume is less than 510 vphpl and if the flow is well organized the system will operate well in NB direction (even though better timing plans may be obtained)

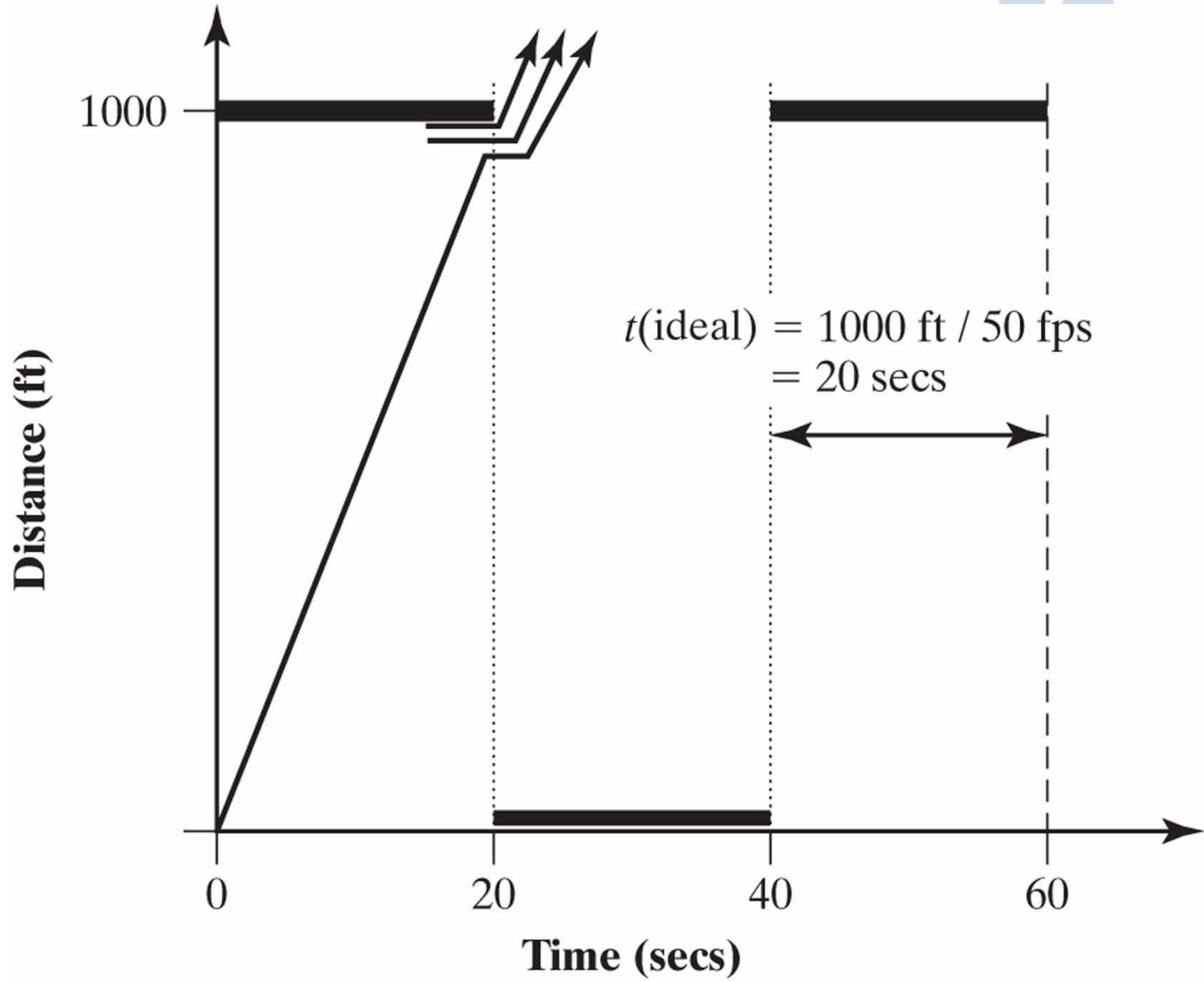
Bandwidth Capacity (3)

$$c_{BW} = \frac{3600 * BW * NL}{C * h}$$

- c_{BW}: Bandwidth capacity
- BW: Bandwidth, sec
- C: Cycle length, sec
- NL: Number of directional through lanes
- h: Saturation headway, sec

- **Note:** The above equation does not contain any factors to account for lane utilization and queuing:

Effect of Queued Vehicles



Effect of Queued Vehicles (2)

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

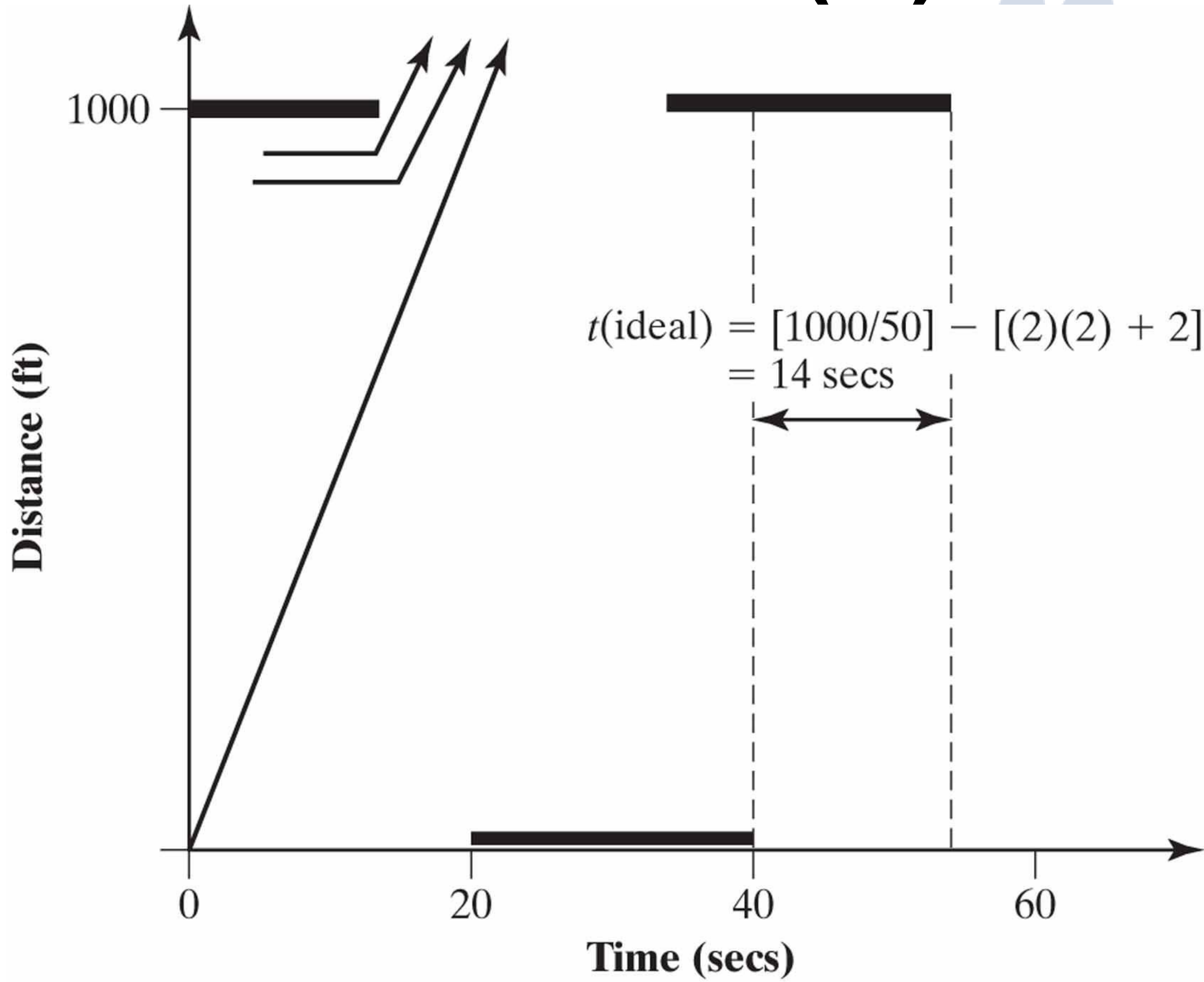
- t_{adj}: Adjusted ideal offset, sec
- L: Distance between signals, ft
- S: Speed, ft/sec
- Q: Number of queued vehicles per lane, veh
- H: Discharge headway of queued vehicles, sec/veh
- l_1: Start-up lost time, sec

Effect of Queued Vehicles (3)

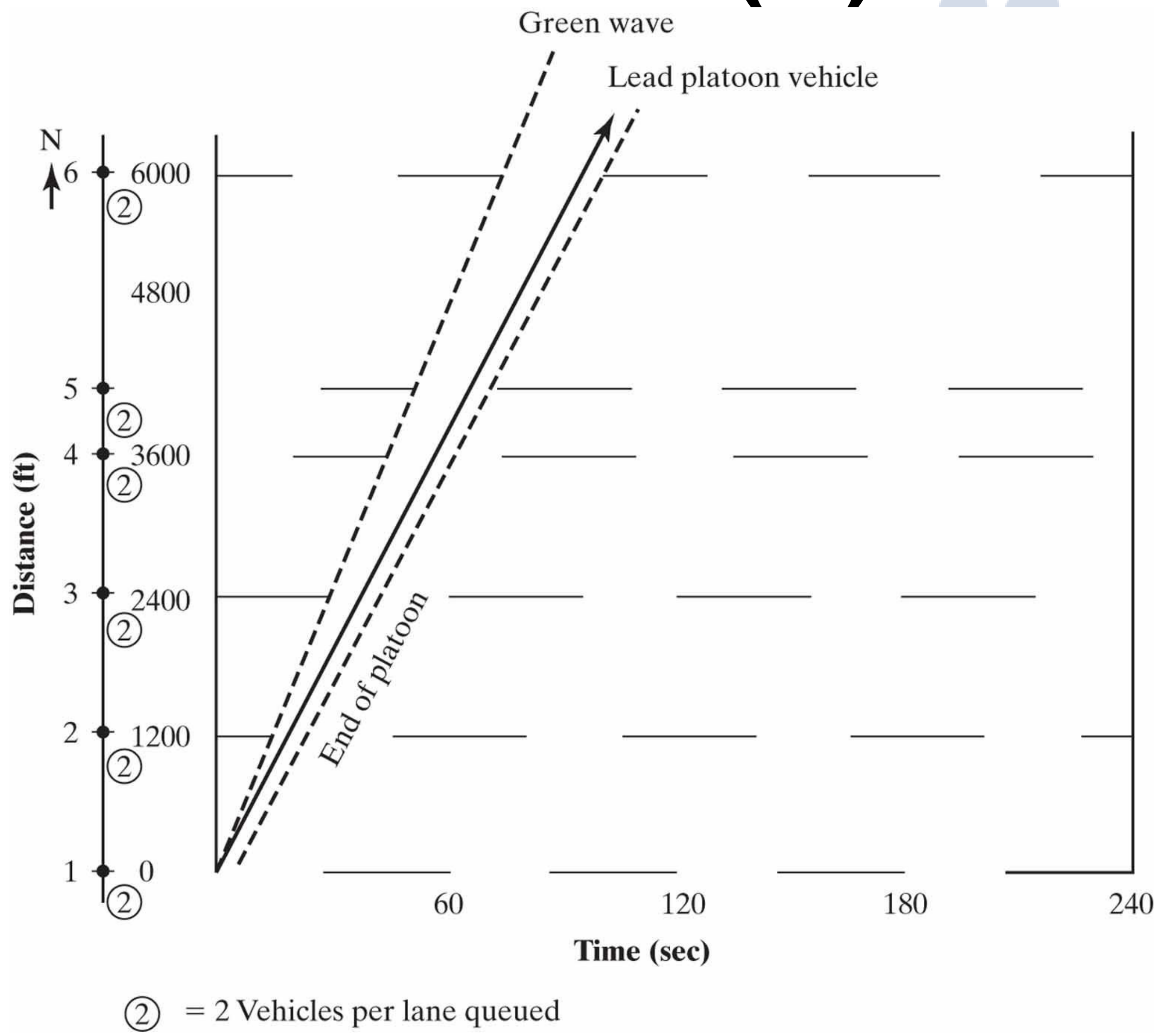
- Note: The start-up lost time is only accounted for first downstream intersection.
  - If the preceding intersections have queue, then they are automatically cleared (because of platoon)

Effect of Queued Vehicles (4)

- Calculate offset if
  - 2 queue veh/cycle
  - Sat. headway 2sec
  - Lost time, 2 sec



Effect of Queued Vehicles (5)



Effect of Queued Vehicles (6)

Table 26.2: Progression Speeds in Figure 26-11

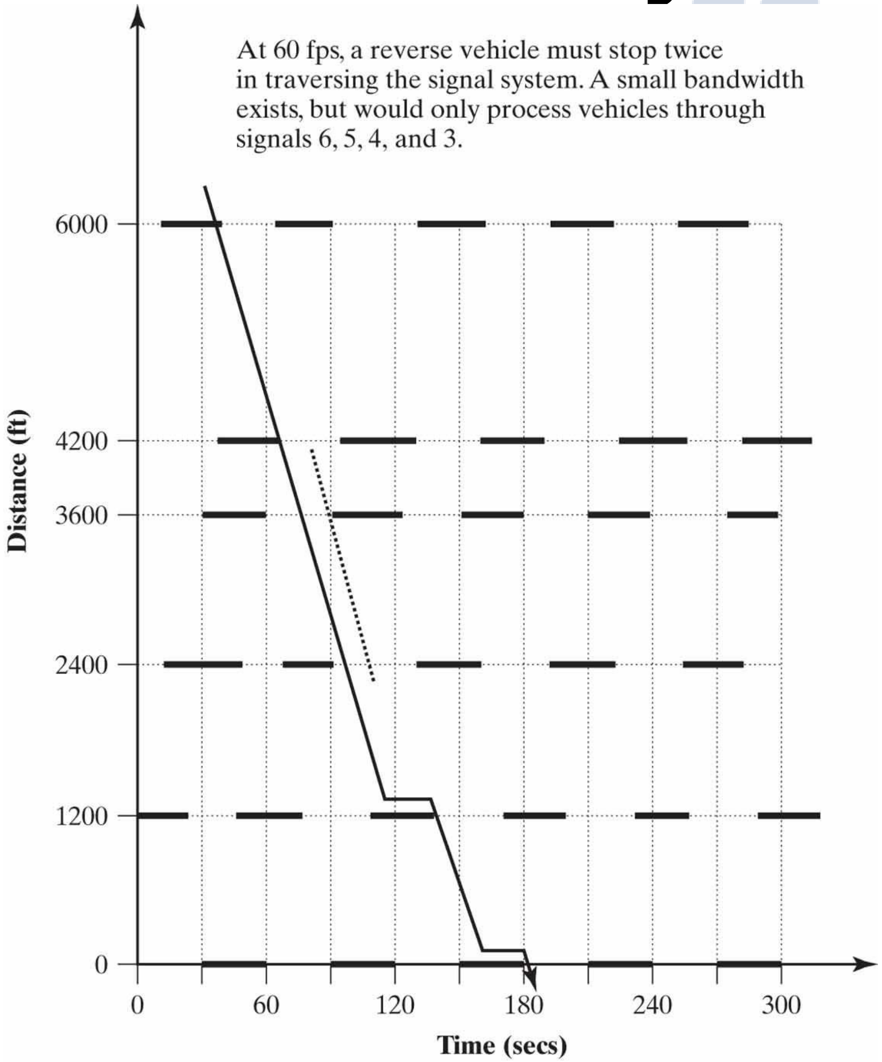
Link	Link Offset (s)	Speed of Progression (ft/s)
Signal 1 $\rightarrow$ 2	(1,200/60) − (4 + 2) = 14	1,200/14 = 85.7
Signal 2 $\rightarrow$ 3	(1,200/60) − (4) = 16	1,200/16 = 75
Signal 3 $\rightarrow$ 4	(1,200/60) − (4) = 16	1,200/16 = 75
Signal 4 $\rightarrow$ 5	(600/60) − (4) = 6	600/6 = 100
Signal 5 $\rightarrow$ 6	(1,800/60) − (4) = 26	1,800/26 = 69.2
Total Offset = 78 sec		

In Class Example-1

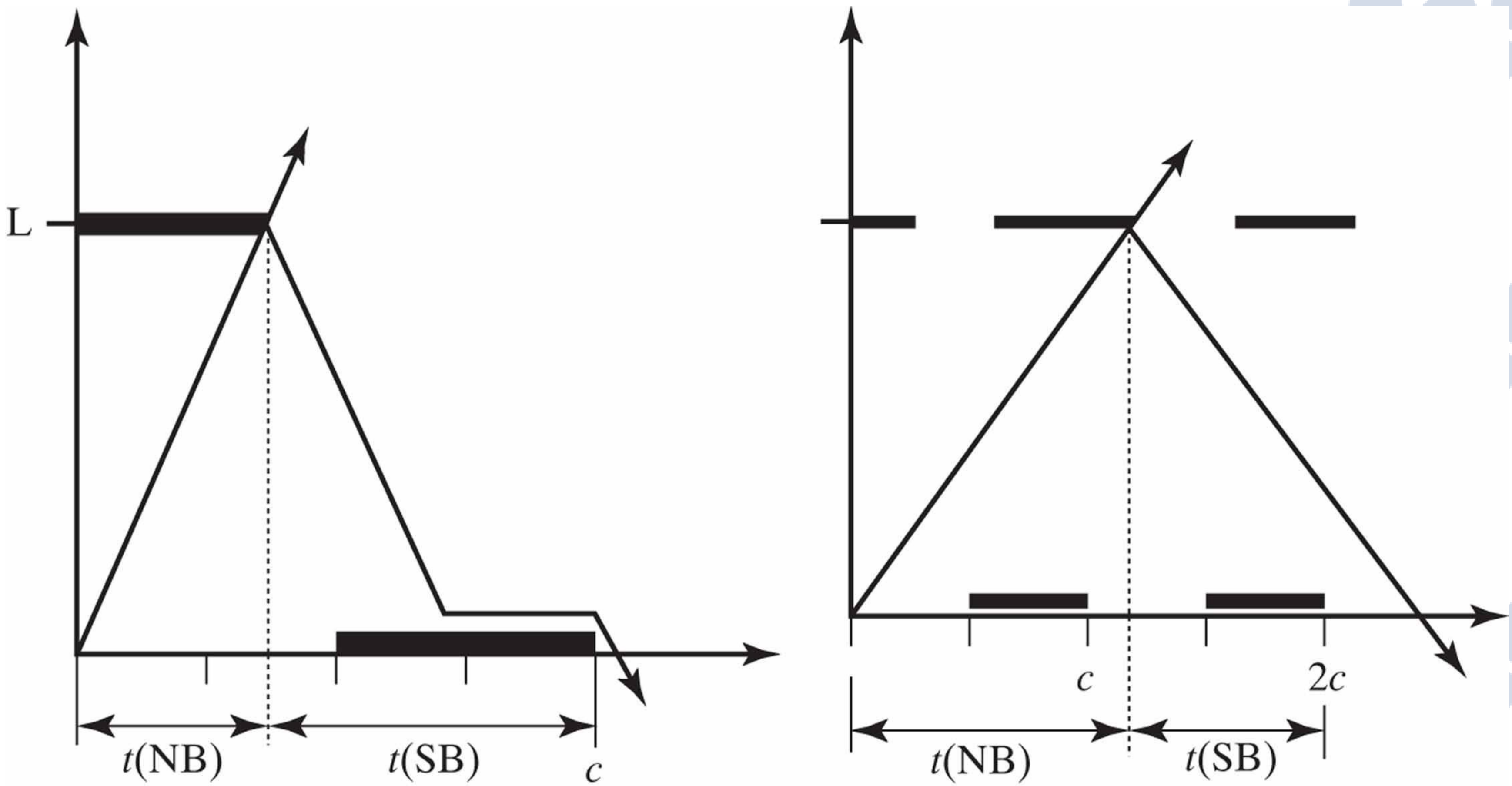
- Two signals are spaced in 1000 ft. The desired progression speed is 40mph, cycle length is 60 sec,
  - What is the ideal offset between two intersections

Signal Progression on Two-way St.

- If NB offset applied to SB
  - Vehicles need to stop twice
  - Lesser bandwidth
  - About 40 sec of delay/veh
  - There is no bandwidth



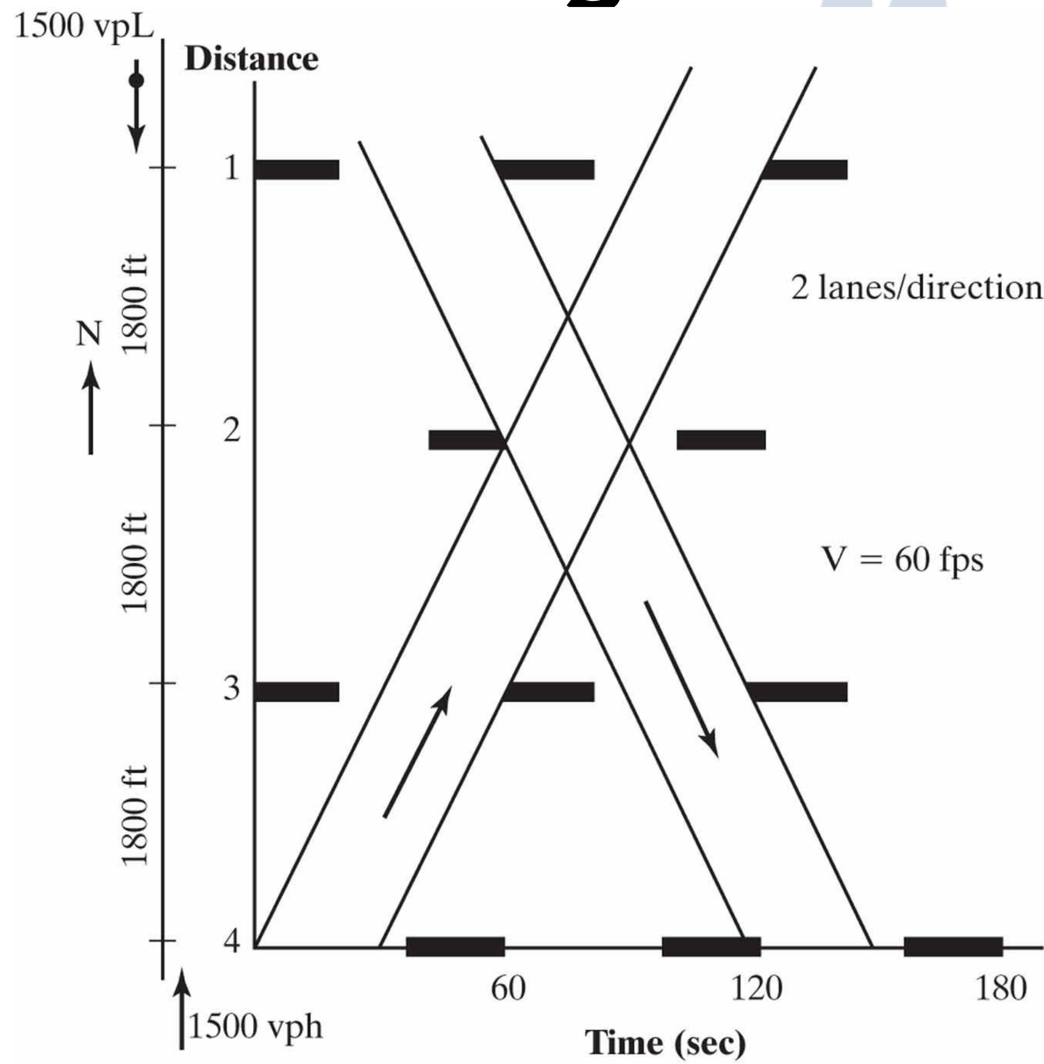
Offsets in Two-way Street



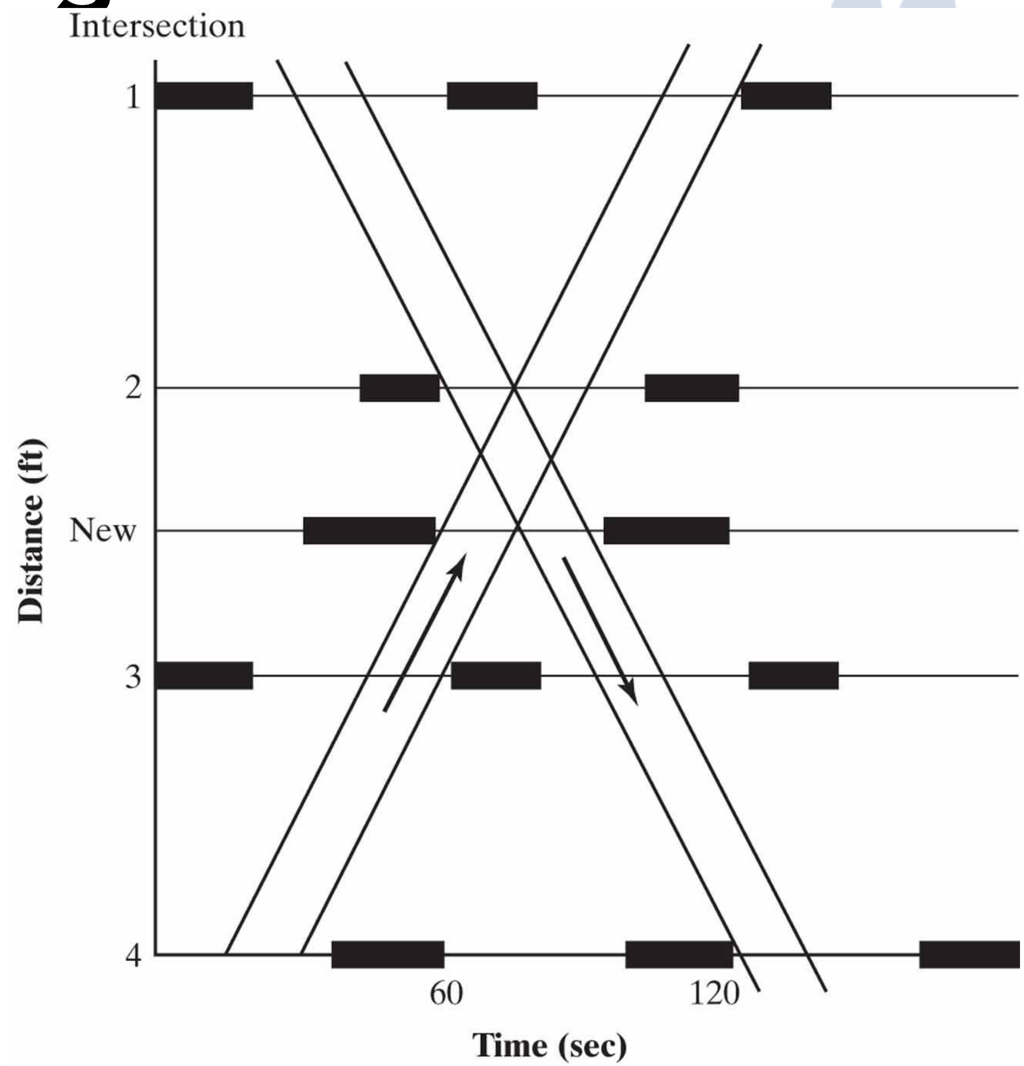
(a) Offsets Add to One Cycle Length

(b) Offsets Add to Two Cycle Lengths

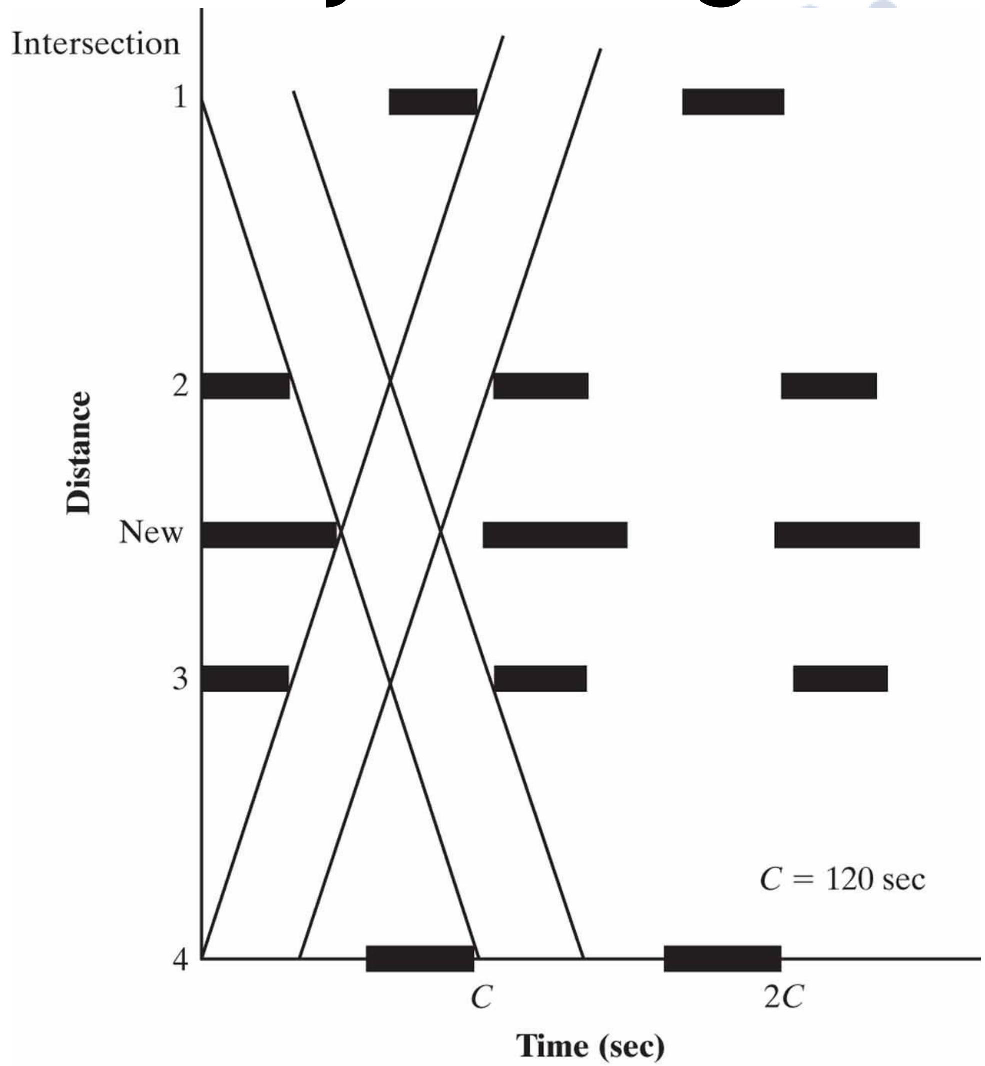
Two-way Street with 4 -Signals



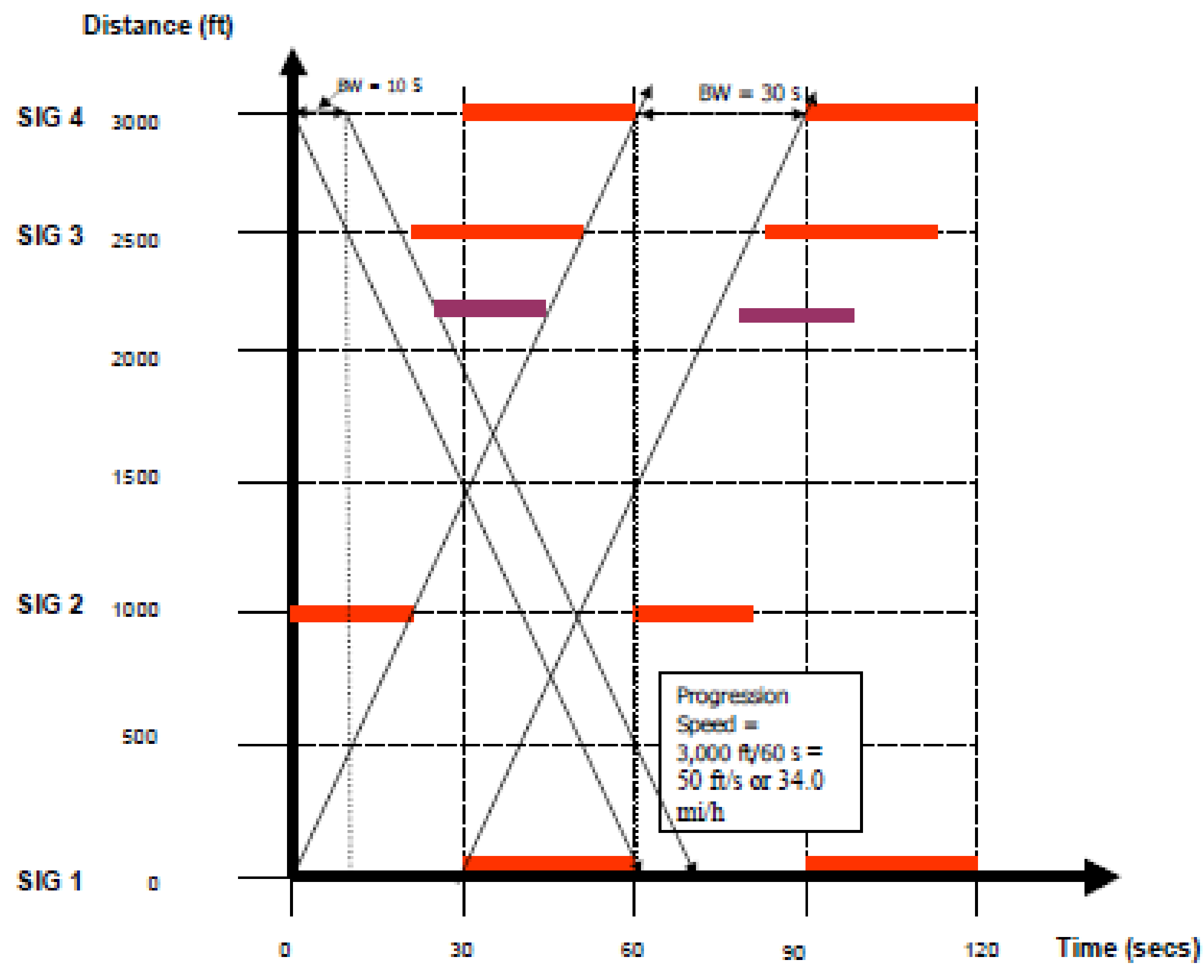
Adding a Fifth Signal



Adding a Signal with Diff. Cycle Length



Example-2 Solution



Common Types of Progression

- The alternate progression
- The double alternate progression
- The simultaneous progression

Alternate Progression (1)

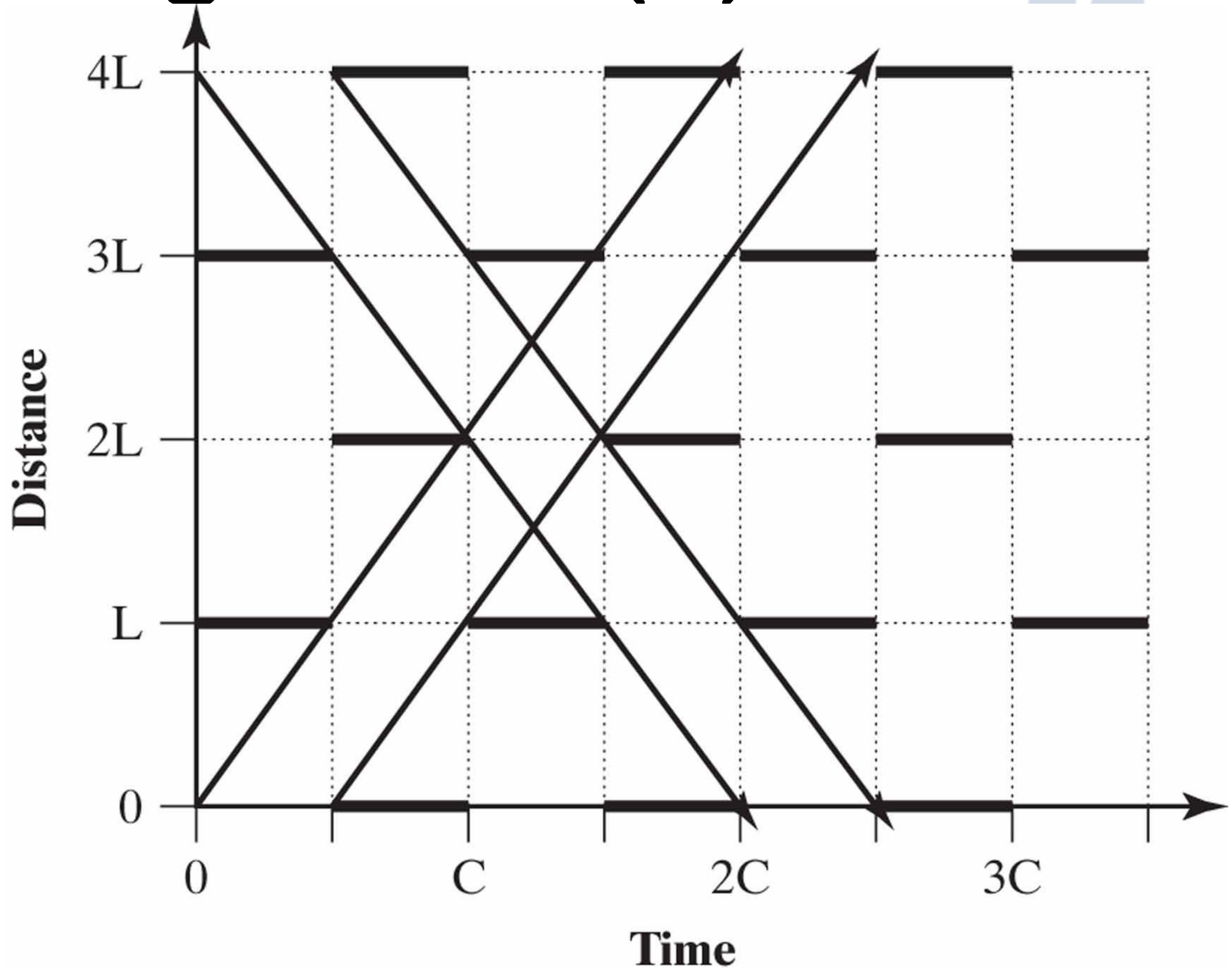
- For certain uniform block lengths, and al intersections with a 50-50 split of effective green time, the cycle length can be selected such that

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

- Bandwidth Capacity

$$c_{BW} = \frac{3600 * BW * NL}{C * h} = \frac{3600 * 0.5C * NL}{C * 2} = 900NL$$

Alternate Progression (2)



Alternate Progression (3)

Table 26.3: Come Illustrative Combinations for Alternate Progression

Cycle Length (s)	Platoon Speed (fps)	Matching Block Length (ft)
60	45	1,350
60	75	2,250
90	45	2,025
90	75	3,375

Double Alternate Progression (1)

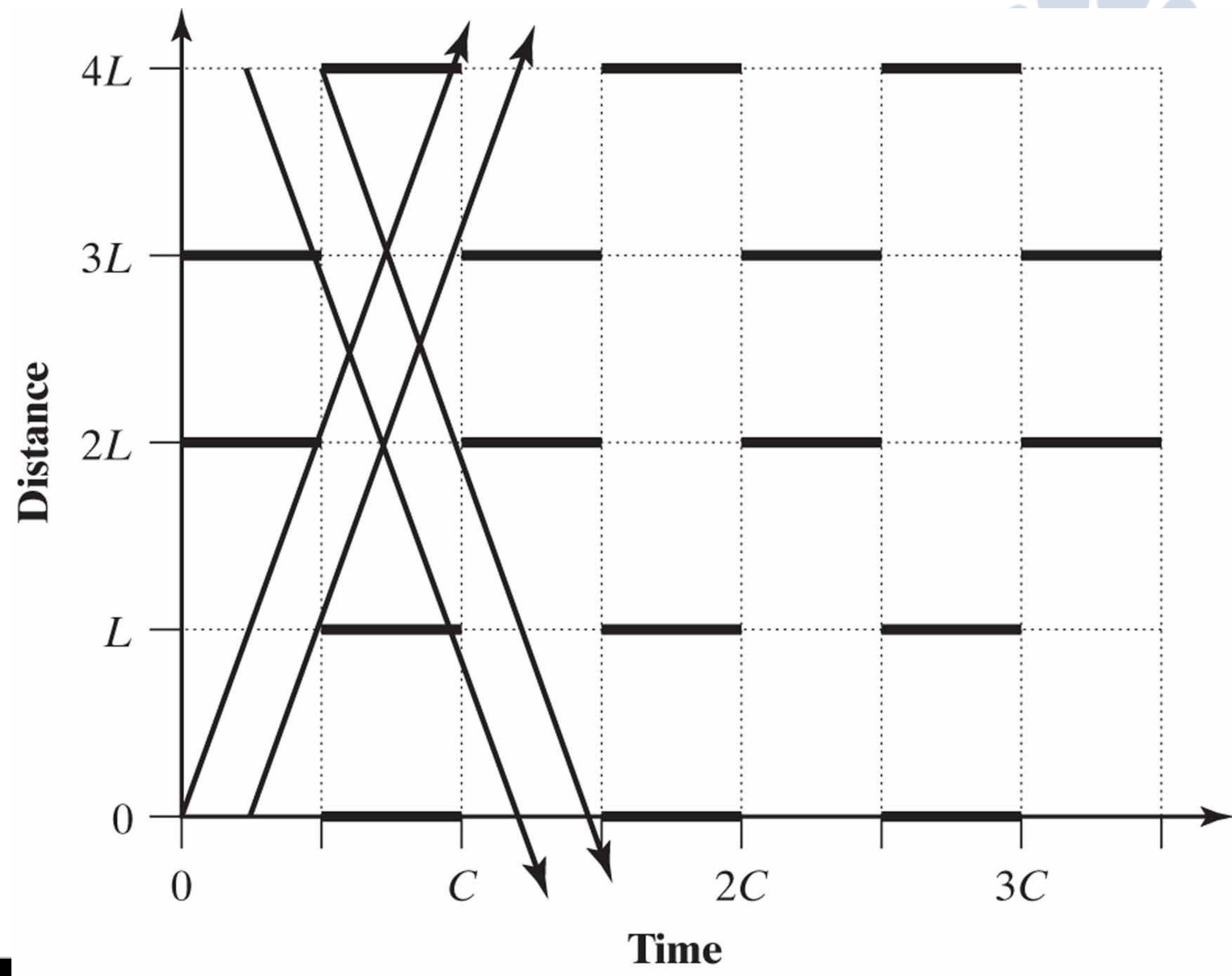
- For certain non-uniform block lengths, 50-50 split of effective green time is not possible, but the it is feasible to select the following cycle length

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

- Bandwidth Capacity

$$c_{BW} = \frac{3600 * BW * NL}{C * h} = \frac{3600 * 0.25C * NL}{C * 2} = 450NL$$

Double Alternate Progression (2)



Double Alternate Progression (3)

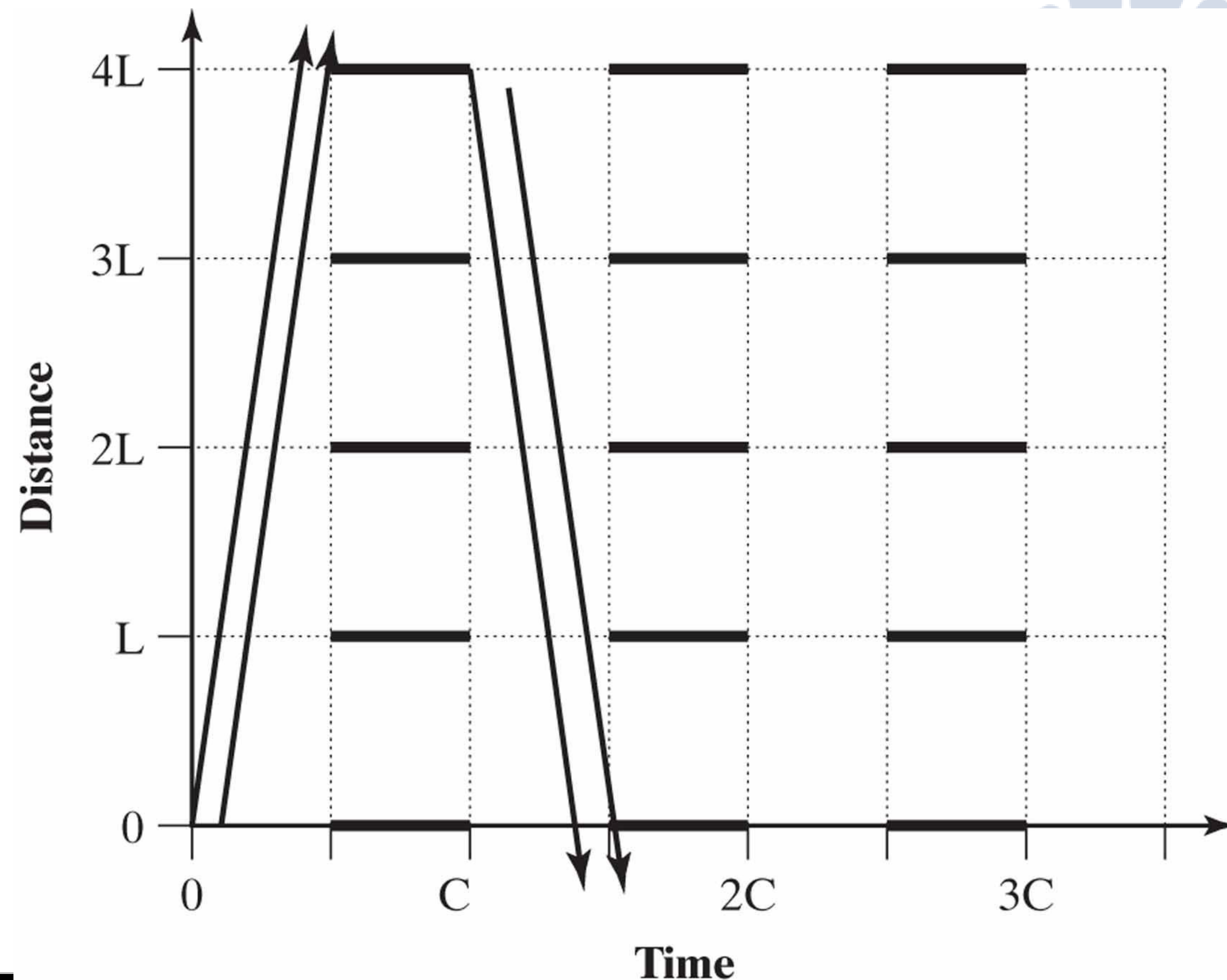
Table 26.4: Illustrative Combinations for Double-Alternate Progression

Cycle Length (s)	Platoon Speed (fps)	Matching Block Length (ft)
60	45	675
60	75	1,125
90	45	1,012
90	75	1,688

Simultaneous Progression

- For very closely spaced signals, or for higher vehicle speeds, it may be best possible to have all the signals turn green at the same time (called as simultaneous system)

Simultaneous Progression (2)



Simultaneous Progression (3)

- The efficiency of simultaneous system depends on number of signals involved.

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

- For four signals with L=400 ft, C=80 sec, S=45 ft/sec
  - What is EFF%?
- Similarly when L = 200 ft, EFF%?

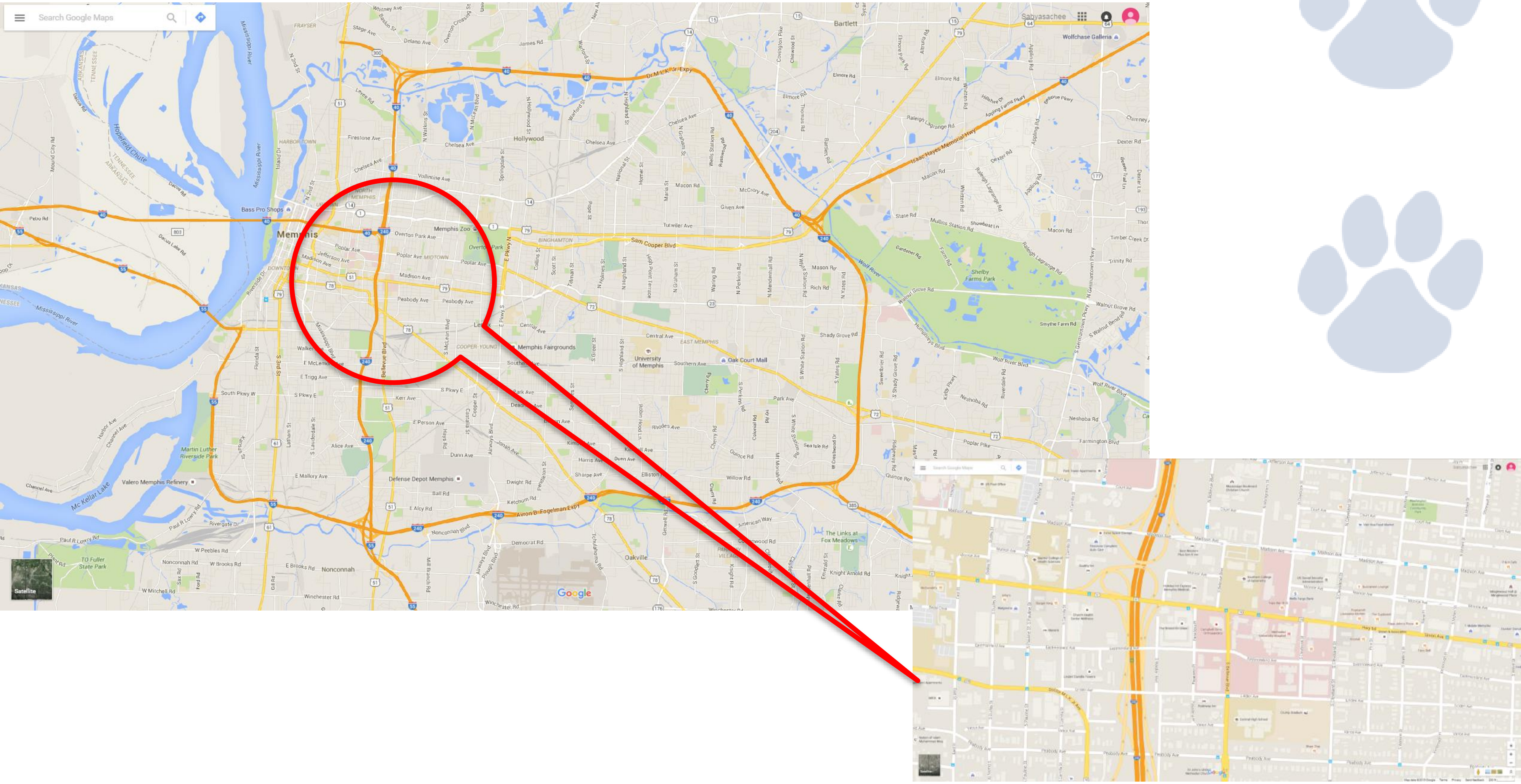
Simultaneous Progression (4)

- Simultaneous signals are advantageous only under special circumstances
  - Block length are very short
  - Relatively higher speed
  - Near CBD

Simultaneous Progression (5)

- Disadvantages
  - May result breakdown and spillback
    - Because queue inevitably exists in downstream
  - Cuts platoons off

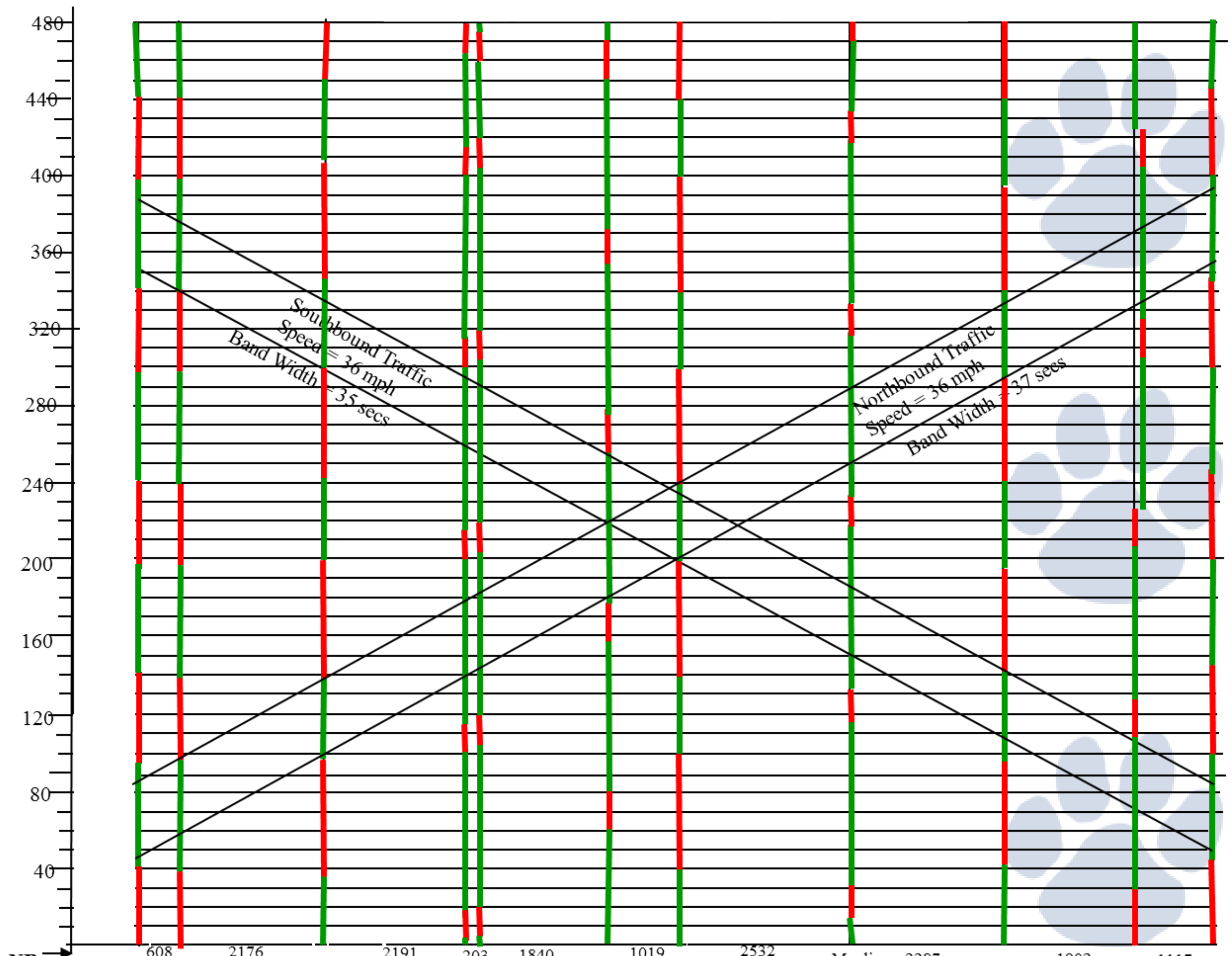
The case of multi-resolution networks



Speed versus Congestion

- **Speed of progression**
  - often selected to be the free-flow speed of traffic
    - Some engineers use it as speed limit.
  - speed that might be observed when volumes are light and the signals are continuously green on that route
- **As traffic becomes heavy (peak periods)**
  - traffic speeds tend to drop because of congestion
  - traffic starting up on a green signal may be stopped by a queue not yet into motion at the next signal downstream

Example



	EB I-696	WB I-696	11 Mile Road	Parkview	Solberg	Universal Mall Drive	12 Mile Road	Moulin	13 Mile Road	Whitcomb	E. Avis
Offset	41	38	98	18	21	80	0	32	95	30	45
Green	56.5	58.5	40	83.5	83.5	80	40	83.5	45	80	56.5
Red	43.5	41.5	60	16.5	16.5	20	60	16.5	55	20	43.5
CL	100	100	100	100	100	100	100	100	100	100	100

Source: Adapted from WSU CIVIL 7670

Other considerations

- Traffic Turning into System
- Adjustments at End Intersections
- Adjustments for Left-Turn Phases
- Offsets for Maximum Bandwidths
- Offsets for Minimum Stops and Delay

Softwares

- Relatively Smaller Networks
  - PASSER II- Optimize bandwidths
  - TRANSYT 7F- Minimizes disutility function
  - NETSIM- Optimizes synchronization
  - Synchro- models and optimizes traffic signals
    - Optimizes to reduce delay
  - SimTraffic- to check and fine tune signal operations
- Medium to Large Networks
  - AIMSUN, VISSUM, TransModeler, Paramics, and others

Next Class (11/30)

- Report Review
- Introduction to queuing theory
- Statistical application in evaluating traffic operational improvements

Final Exam and Report Due

- Final exam: 12/7 (1 hour)
- Project presentations (30 minutes from each group)
- Report due at the beginning of class, 12/7