Signal Coordination

• For situations with relatively closely spaced intersections

• Vehicles commonly maintain their grouping for well over 1000 feet. Common practice is to coordinate signals less than ½ mile apart on major streets and highways
Figure 22-1  Illustrative vehicle trajectory.
Benefits

Prime benefit: reduction in stops and delays

It is common to consider the benefit of a coordination plan in terms of costs as a weighted combination of stops and delay:

\[ \text{Cost} = A \times (\text{total stops}) + B \times (\text{total delay}) + \text{other terms} \]

- Encourage preferred speed: signals set such that to incur more stops for speeds faster than the design speed
- Set up platoons (shorter headways)

Stop fewer vehicles, esp important for short blocks with heavy flows which may overflow the available storage
Note that neither offsets are computed using Equation (b) Offset

Figure 24.2:

(a) Stops

(b) Delay

600-ft block
600 vph in two lanes
all through traffic
free speed 24 mph
50:50 split
60 s cycle length
Factors lessening benefits

- Inadequate roadway capacity
- Existence of substantial side frictions, including parking, loading, double parking, and multiple driveways
- Complicated intersections, multiphase control
- Very short signal spacing
- Heavy turn volumes, either into or out of the street
Exceptions to the coordinated scheme

- Easy coordination may not always be possible. For example, a very busy intersection located in not as congested area. The engineer may not want to use the cycle time of the busy intersection as the common cycle time.

- Another example is the existence of a critical intersection that causes queue spillback.
The time-space diagram and ideal offsets

- Offset: the difference between the green initiation times at two adjacent intersections.
  - usually expressed as a positive number between zero and the cycle length.
- Often, the ideal offset: the value such that the first vehicle of a platoon just arrives at the downstream signal, the downstream signal turns green.

  \[ t(\text{ideal}) = \frac{L}{S} \] where \( L \) = block length, \( S \) = vehicle speed

  Offset = mod C \{OFFSET\}
Lecture 12: Selected topics in signalized intersections

a. Time-space diagram
The Time-Space Diagram and Ideal Offsets

Distance (ft)

First Vehicle Trajectory

Last Possible Vehicle Trajectory

Bandwidth

\[ t_1 \]

Time (s)

\[ v \]

\[ 1 \]

\[ S \]

\[ t_{ideal} = \frac{S}{v} (24 - 1) \]

where:

- \( t_{ideal} \) = ideal offset
- \( S \) = average speed, ft
- \( f \) = time

The "ideal offset" is defined as exactly the offset such that, as the first vehicle of a platoon just arrives at the downstream signal, the downstream signal turns green. It is usually assumed that the platoon was moving as it went through the upstream intersection. If so, the ideal offset is given by Equation 24-1.
Signal Progression for One-Way Streets

Figure 24.3: Case Study in Progression on a One-Way Street

Table 24.1: Ideal Offsets for Case Study

Signal Progression

See the pattern that results, the time-space diagram should be constructed according to the following rules:

1. The vertical should be scaled so as to accommodate the dimensions of the arterial, and the horizontal so as to accommodate at least three to four cycle lengths.

2. The beginning intersection (Number 1, in this case) should be scaled first, usually with main street green (MSG) initiation at $t = 0$, followed by periods of green and red (yellow may be shown for precision). See Point 1 in Figure 24.4.

3. The main street green (or other offset position, if MSG is not used) of the next downstream signal should be located next, relative to $t = 0$. 

Lecture 12: Selected topics in signalized intersections
Figure 24.3: Case Study in Progression on a One-Way Street

Table 24.1: Ideal Offsets for Case Study

1. The vertical should be scaled so as to accommodate the dimensions of the arterial, and the horizontal so as to accommodate at least three to four cycle lengths.

2. The beginning intersection (Number 1, in this case) should be scaled first, usually with main street green (MSG) initiation at $t = 0$, followed by periods of green and red (yellow may be shown for precision). See Point 1 in Figure 24.4.

3. The main street green (or other offset position, if MSG is not used) of the next downstream signal should be located next, relative to $t = 0$. Point 3

Point 2

Point 1
and at the proper distance from the first intersection. With this point located (Point 2 in Figure 24.4), fill in the periods of effective green and red for this signal.

4. Repeat the procedure for all other intersections, working one at a time. Thus, for Signal 3, the offset is located at point 3, 20 s later than Point 2, and so on.

Figure 24.4 has some interesting features that can be explored with the aid of Figure 24.5.

First, if a vehicle (or platoon) were to travel at 60 fps, it would arrive at each of the signals just as they turn green; this is indicated by the solid trajectory lines in Figure 24.5. The solid trajectory line also represents the speed of the "green wave" visible to a stationary observer at Signal 1, looking downstream. The signals turn green in order, corresponding to the planned speed of the platoon, and give the visual effect of a wave of green opening before the driver.

Third, note that there is a "window" of green in Figure 24.5, with its end indicated.

Equal bandwidths of 30 seconds provided under ideal progression by the dotted trajectory line; this is also the trajectory of the last vehicle that could travel through the progression without stopping at 60 ft/s. This "window" is the bandwidth, as defined earlier. Again, in this case it equals the green time because all signals have the same green time and have ideal offsets.

24.2.2 Potential Problems

Consider what would happen if the actual speed of vehicle platoons in the case study was 50 ft/s, instead of the 60 ft/s anticipated. The green wave would still progress at 60 ft/s, but the platoon arrivals would lag behind it. The effect of this on bandwidth is enormous, as shown in Figure 24.6. Only a small window now exists for a test vehicle at 50 fps passes through all signals without stopping. Bandwidth is reduced to a very small value.
4. Repeat the procedure for all other intersections, working one at a time. Thus, for Signal 3, the offset is located at point 3, 20 s later than Point 2, and so on.

Figure 24.4 has some interesting features that can be explored with the aid of Figure 24.5. First, if a vehicle (or platoon) were to travel at 60 fps, it would arrive at each of the signals just as they turn green; this is indicated by the solid trajectory lines in Figure 24.5. The solid trajectory line also represents the speed of the "green wave" visible to a stationary observer at Signal 1, looking downstream. The signals turn green in order, corresponding to the planned speed of the platoon, and give the visual effect of a wave of green opening before the driver.

Third, note that there is a "window" of green in Figure 24.5, with its end indicated by the dotted trajectory line; this is also the trajectory of the last vehicle that could travel through the progression without stopping at 60 ft/s. This "window" is the bandwidth, as defined earlier. Again, in this case it equals the green time because all signals have the same green time and have ideal offsets.

24.2.2 Potential Problems
Consider what would happen if the actual speed of vehicle platoons in the case study was 50 ft/s, instead of the 60 ft/s anticipated. The green wave would still progress at 60 ft/s, but the platoon arrivals would lag behind it. The effect of this on bandwidth is enormous, as shown in Figure 24.6. Only a small window now exists for a test vehicle at 50 fps to pass through all signals without stopping. Bandwidth is reduced to a very small value.
A test vehicle at 70 fps arrives at signals too soon and experiences slight delay. Bandwidth is decreased as shown.

Figure 24.7 shows the effect of the vehicle traveling faster than anticipated, 70 ft/s in this illustration. In this case, the vehicles arrive a little too early and are delayed; some stops will have to be made to allow the "green wave" to catch up to the platoon. In this case, the effect on bandwidth is not as severe as in Figure 24.6. In this case, the bandwidth impact of underestimating the platoon speed (60 ft/s instead of 70 ft/s) is not as severe as the consequences of overestimating the platoon speed (60 ft/s instead of 50 ft/s).

Bandwidth is defined as the time difference between the first vehicle that can pass through the entire system without stopping and the last vehicle that can pass through without stopping, measured in seconds. The bandwidth concept is very popular in traffic engineering practice because the windows of green are easy visual images for both working professionals and public presentations. The most significant shortcoming of designing offset plans to maximize bandwidths is that internal queues are often overlooked in the bandwidth approach.

Lecture 12: Selected topics in signalized intersections
Effect of vehicles queued at signals

\[ t(\text{ideal}) = \frac{L}{S} - (Q \cdot h + \text{Loss}) \]

where \( Q \) = # veh queued per lane, \( h \) = discharge headway (\( \sim 1.9 \) s), \( \text{Loss} \) = loss time associated with vehicles starting from rest at the first downstream signal (\( \sim 2 \) s)

**A note on queue estimation**

- It is a difficult and expensive task to estimate the queue size from cycle to cycle.
Figure 22-8 Effect of vehicles queued at a signal.
The number of vehicles queued in advance is the sum of the number of vehicles that can be accommodated in each link as shown in Table 24.10.

In general terms, the number of vehicles queued in advance is given by the following equation:

\[
N = (1,200 / 60) - (1,800 / 26) + (600 / 6) - (24,426 / 24.5) + (3,600 * BW * L - 24)
\]

where:

- \( N \) = number of vehicles queued in advance
- \( 1,200 / 60 \) = vehicles entering the intersection
- \( 1,800 / 26 \) = vehicles clearing out the queue
- \( 600 / 6 \) = vehicles from upstream signals
- \( 24,426 / 24.5 \) = vehicles in advance
- \( 3,600 * BW * L \) = vehicles that can be accommodated
- \( 24 \) = number of links

The effect in some limit beyond which the offset plan is not ideal is depicted in Fig. 24.9.

Average speed = 50 ft/s

The visual image of the traffic signal progression speed is much faster, due to the ideal offset plan.

The offset plan is sometimes referred to as the modified ideal offset plan.

The nearest signal arrives. This is called queuing.

The following equation:

\[
t_{adj} = \left[ \frac{1,000}{50} \right] - \left[ \frac{(2)(2) + 2}{(2)} \right]
\]

\[
= 14 \text{ s}
\]

Average speed = 50 ft/s

The offset plan is often used to improve the flow of traffic.
Offset determination on a two-way street

- The fact that the offsets are interrelated presents one of the most fundamental problems of signal optimization.

- Actual offsets and travel times are distinct. While the engineer might desire the ideal offset to be the same as the travel time

- In link i, the actual offsets are related by:

\[ t_{NB,i} + t_{SB,i} = nC \]

- Define the actual offset and ideal offset by:

where \( j \) represents the direction, and \( i \) the link
Distance

\[ t_{NB} \]

\[ t_{NB} + t_{SB} = C \]

(a) Offsets add to one cycle length
(b) Offsets add to two cycle lengths
Offset Optimization

- Define the actual offset and ideal offset by:

\[ t_{actual}(j,i) = t_{ideal}(j,i) + e(j,i) \]

where \( j \) represents the direction, and \( i \) the link

- In a number of signal optimization programs that can be used for two-way arterials, the objective is to minimize some functions of the discrepancies between the actual and ideal offsets.

- The simplest form is perhaps the sum of the squares or of the discrepancies, weighted by the link volumes:

\[ Z = \sum_{j,i} \left[ v(j,i) \left( t_{actual}(j,i) - t_{ideal}(j,i) \right)^2 \right] \]
The bandwidth concept and maximum bandwidth
Bandwidth and efficiency of a progression

- Efficiency defined as:
  
  Efficiency = \frac{\text{bandwidth}}{\text{cycle length}} \times 100\%

- An efficiency of 40-55% is considered as good. The bandwidth is limited by the min green in the direction of interest.

- Nonstop volume = 3600 \times \frac{\text{BW} \times L}{h \times C} \text{ vph}

Where BW = measured or computed bandwidth (s); L = number of through lanes; h = headway (s/veh), C = cycle length (s)
Effective progressions on 2-way Streets

- If an appropriate combination of cycle length, block length, and platoon speed, then the task of good progression in both directions becomes easy.

- Therefore, whenever possible, in new town or new development, these “appropriate combinations” must be considered seriously.
Figure 22-19  Effect of inserting a new signal into system.
Figure 22-20  A solution to the case study with $C = 120$ seconds by increasing the slope of the vehicle guideline.
Unequally Spaced Intersections

Old Green Band in North Direction (NEMA 2)

New Green Band in South Direction (NEMA 6)

Old Green Band in North Direction (NEMA 2)

New Green Band in South Direction (NEMA 6)
Regain Green Band in North Direction (NEMA 2)

Lose Green Band in South Direction (NEMA 6)
Regain Green Band in North Direction (NEMA 2)

Regain Green Band in South Direction (NEMA 6)
ORIGINAL PHASING DIAGRAM
for Intersection 2
(Equally-Spaced Intersections)

REVISED PHASING DIAGRAM
for Intersection 2
(Unequally-Spaced Intersections)
Effect of Platoon Dispersion

![Diagram of Platoon Dispersion](image_url)

Source: Reference [23]