CHAPTER 3 – STUDIES OF TIME AND DISTANCE

Overview of Chapter

Our goal in the design of a coordinated traffic control system is for a traveler to arrive at each intersection when the display is green. More often, vehicles travel in platoons but the goal remains the same. When the platoon of vehicles arrives at an intersection, the display should be green, and should stay green long enough to serve the entire platoon. The concept of a platoon traveling from one intersection to the next without stopping is called progression. The signal timing that results in progression is called coordination. The concept that green is displayed long enough to serve the platoon is called bandwidth.

Both progression and bandwidth are fundamental concepts in a coordinated traffic control system. The ability to achieve progression with sufficient bandwidth is dependent on three factors:

1. The distance between the intersections,
2. The speed that vehicles can travel between the intersections, and
3. The length of the signal cycle.

This chapter provides readings and activities in which you will explore how time and distance determine whether progression is possible (for which traffic movements) and with how much bandwidth. You will explore the relationship between the three factors listed above by studying example traffic control systems for one-way streets, two-way streets, one-way grids, and two-way grids. You will see that under certain conditions (combinations of distance between intersections, the speed that vehicles travel, and the length of the signal cycle), progression with bandwidth is possible. But you will also learn that, more commonly, you must make a choice to provide progression to one travel direction or to one traffic movement. These choices will likely result in limited or no progression to the other directions or movements. Or, you might only be able to achieve progression for a portion of one direction. Based on these studies of time and distance, you will be able to identify conditions in which progression is possible and those for which it is not. You will be able to describe the relationship between the distance between two intersections, the vehicle speed, and the cycle length that generates the practical conditions in which progression is possible.

Terms and Concepts

- Cycle length
- Offset
- Split or green split
- Platoon length
- Bandwidth
- Speed

Activity 1 (Reading): The Most Basic Case: One-Way Streets

The downtown area of Portland, Oregon is based on a grid or network of mostly one-way streets covering more than 100 city blocks. (See Figure 1). The network serves more than 50,000 travelers on an average weekday, who travel in automobiles, buses, and light rail trains. The network is controlled by signalized intersections that are spaced about 280 feet apart. And, as in most downtowns, there are lots of pedestrians.

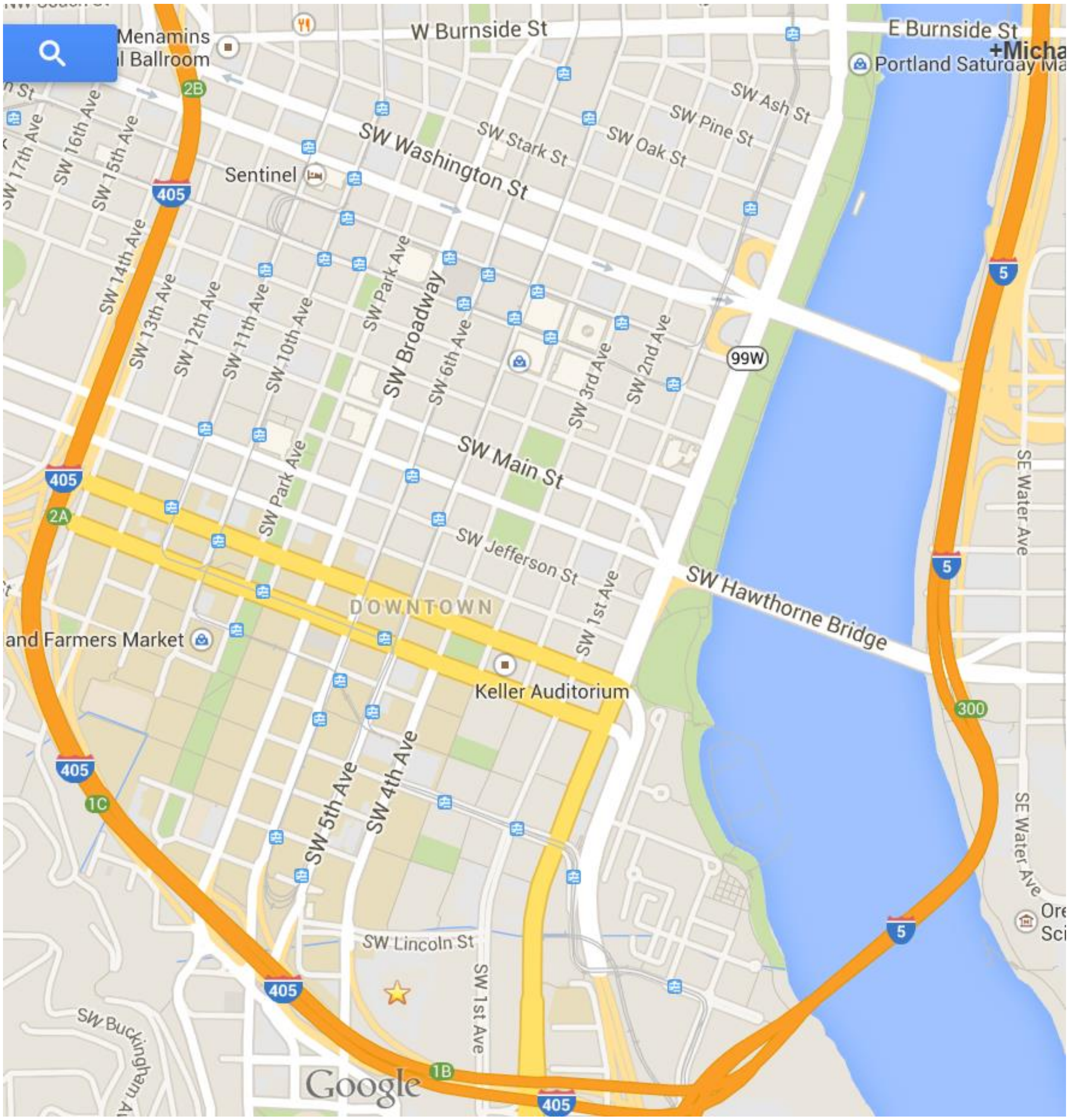


Figure 1. Downtown Portland, Oregon

Suppose you are driving your car northbound on 4th Avenue as part of a platoon of ten vehicles. A portion of 4th Avenue is shown in Figure 2. You arrive at Yamhill Street just as the signal display changes to green. Morrison Street, the next signalized intersection downstream, is 280 feet away. When should the signal display at Morrison Street turn green so that your platoon does not need to stop? The average travel speed in downtown Portland is 13 mi/hr, so the travel time from Yamhill to Morrison is 14.7 sec.

$$travel\ time = \frac{3600L}{5280S} = \frac{(3600)(280\ ft)}{(5280)(13\frac{mi}{hr})} = 14.7\ sec$$

where

L = distance between the intersections, ft, and

S = travel speed, mi/hr

We say that in order to achieve progression on 4th Street the time that green starts at Morrison Street is offset by 14.7 seconds with respect to the start of green at Yamhill Street. The term offset will be defined more precisely in Chapter 4. But for our purposes now, this definition is sufficient. We can state this principle for coordinated signal systems controlling traffic on one-way streets:

> Principle: For a one-way street, the offset which enables a vehicle to travel from one intersection to the next without stopping is equal to the travel time between the two intersections.

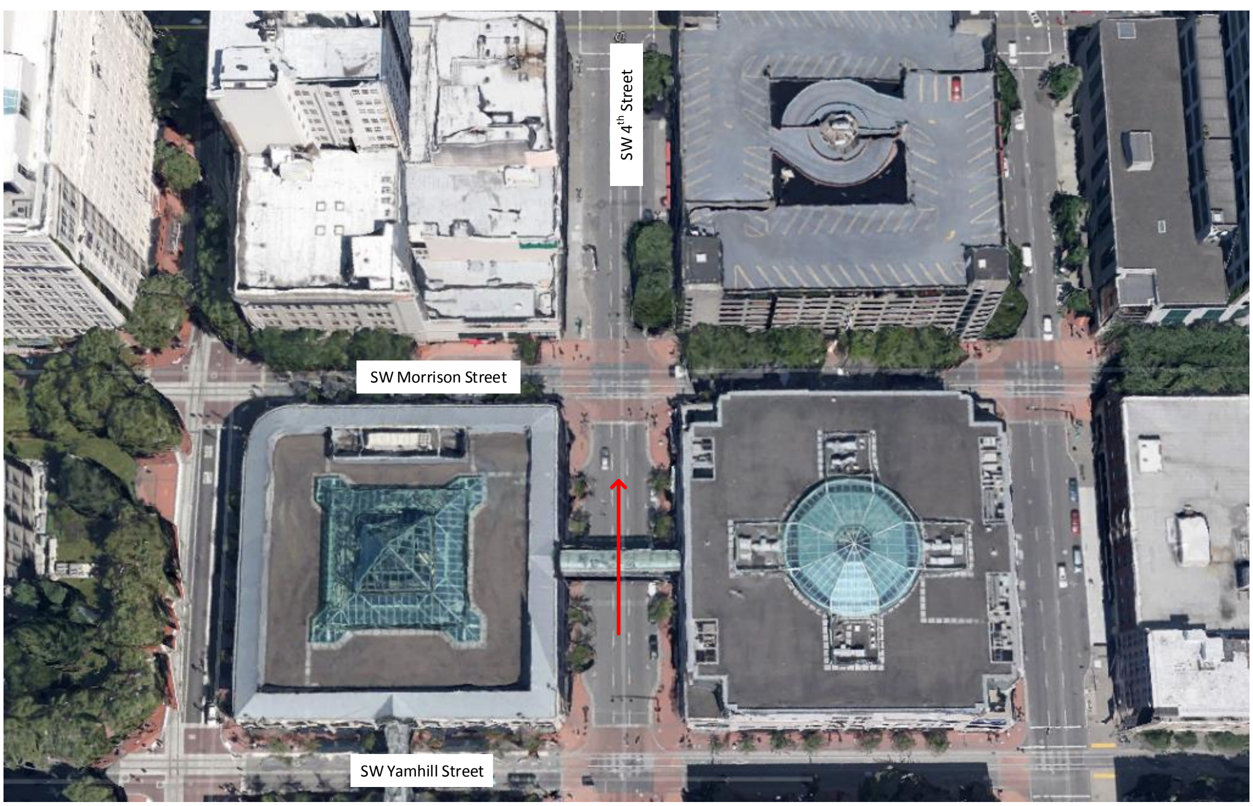


Figure 2. 4th Avenue between Yamhill and Morrison Streets

Another question to ask is how long does green need to be displayed in order for the platoon of ten vehicles to travel through the intersection without any of the vehicles having to stop. Let's say that the average headway between vehicles is 2.5 seconds. Then the green duration must be at least 25 seconds to accommodate the platoon of ten vehicles. These conditions are illustrated in Figure 3, in the form of a time distance diagram.

> Definition: Bandwidth is the duration of time between the arrival of the first vehicle in the platoon and the last vehicle in the platoon

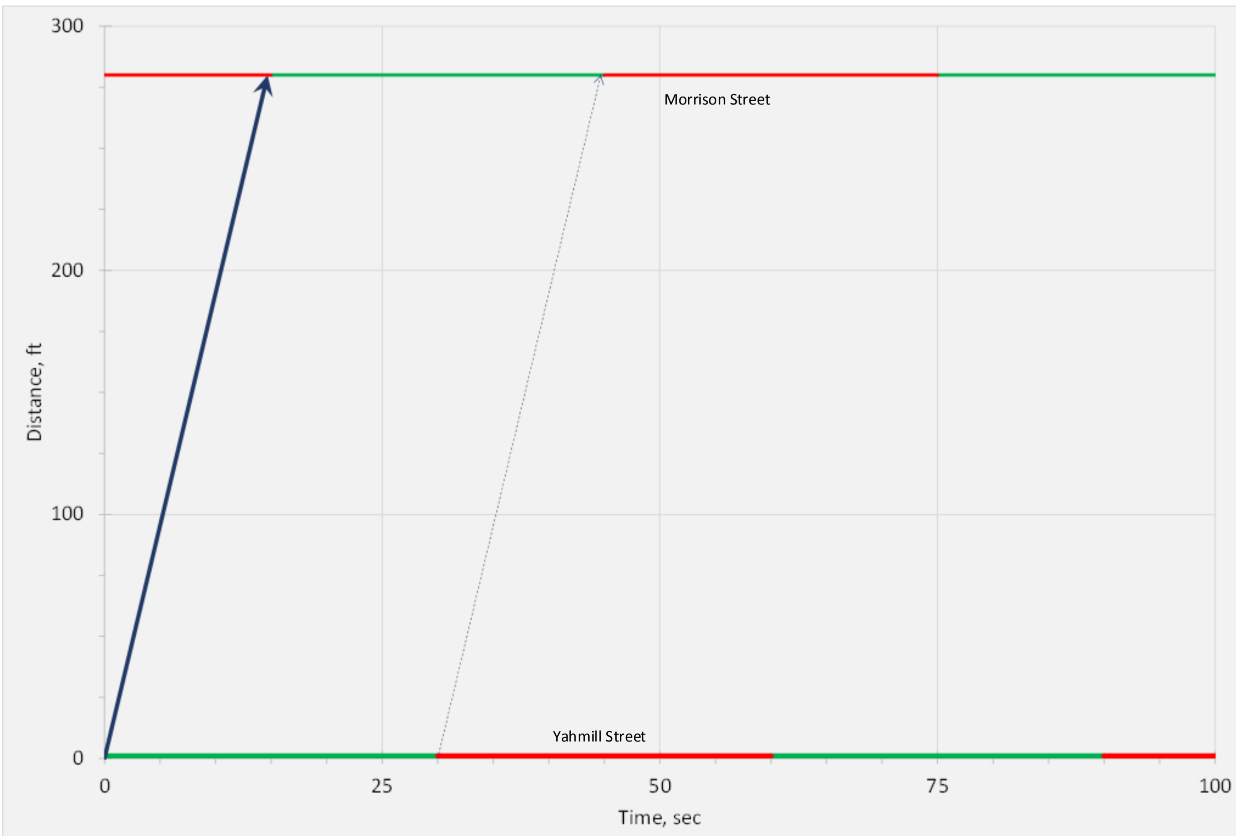


Figure 3. Bandwidth and platoon size, One Way Operation

This example shows that for the given distance of 280 feet between the intersections in which vehicles can travel at an average speed of 13 miles per hour, progression can be provided with an offset of 14.7 seconds and with a bandwidth of 25 seconds. The bandwidth results in a capacity of 10 vehicles during the cycle.

But suppose 4th Avenue operated as a two-way street, with all of the same conditions as for the one-way operation described above. Figure 4 shows that the southbound platoon (down direction in the figure) arrives at Yamhill Street from Morrison Street just as the signal display turns to red. This example illustrates that while it is relatively easy to design a coordinated signal timing plan for a one-way street it is much more challenging (and in some cases impossible) to design a coordinated timing plan for two-way operation. We will explore these challenges of coordination along a two-way street in the next section and the conditions under which progression is possible.

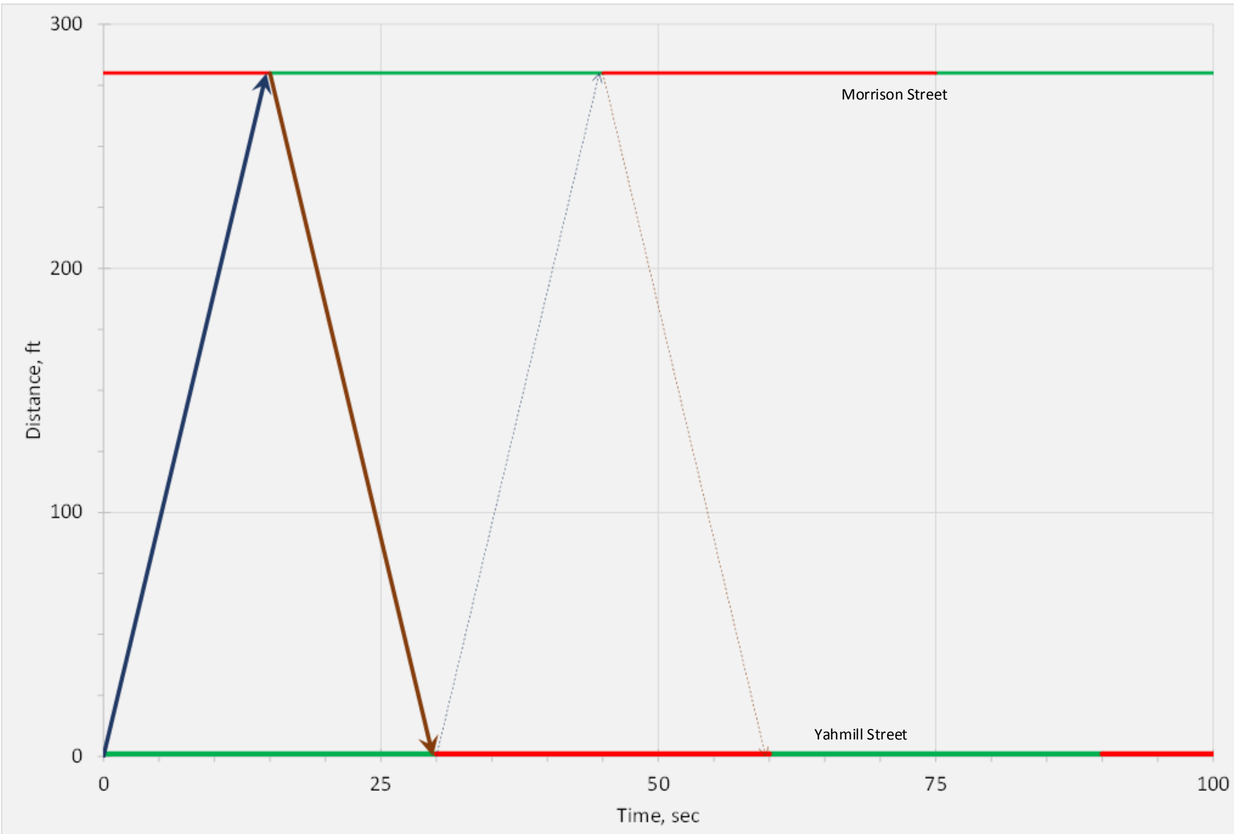


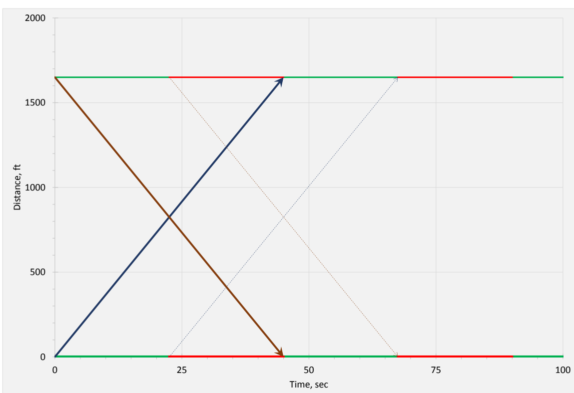
Figure 4. Bandwidth and Platoon Size, Two Way Operations

Activity 2 (Reading): Two-Way Street Operation – Some Examples

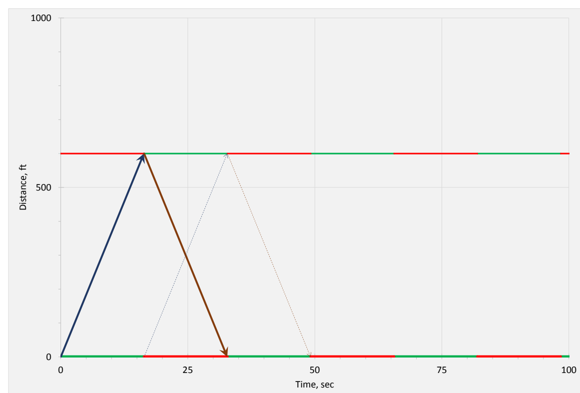
Let's consider four examples of a two-way street bounded at either end by signalized intersections. Table 1 shows the data for each of these four examples and Figure 5 shows the time-space diagrams that result. The dark line in each direction represents the trajectory of the first vehicle in the platoon while the lighter dashed line represents the last vehicle in the platoon. In each case, there is (perfect?) progression of traffic between the two intersections, in both directions. The first vehicle arrives at the downstream intersection just as the signal changes to green, while the last vehicle clears the downstream intersection just as the display changes to red

Table 1

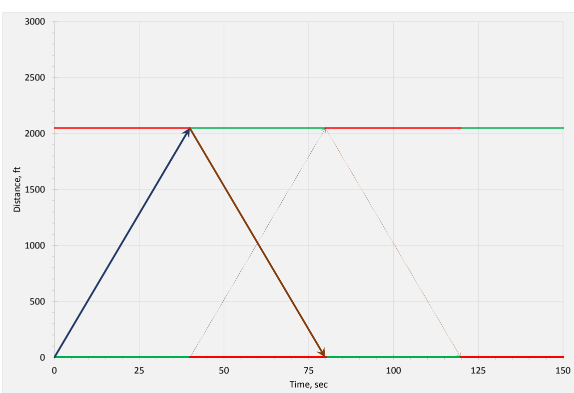
Case	L (ft)	C (sec)	V (mi/hr)	V (ft/sec)
1	1650	45	25	36.75
2	600	32.8	25	36.75
3	2050	80	35	51.5
4	4000	100	55	80.9



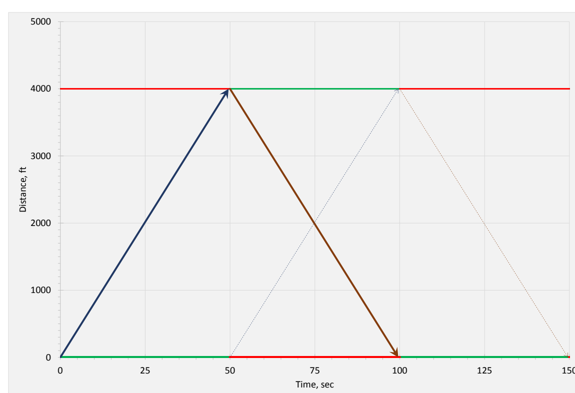
Intersection spacing = 1650 ft



Intersection spacing = 600 ft



Intersection spacing = 2050 ft



Intersection spacing = 4000 ft

Figure 5

These four examples can be used to show the fundamental relationship between cycle length, the distance between the intersections, and the speed of the vehicles traveling from one intersection to the next. Table 2 illustrates part of this fundamental relationship. The last column in the table is the ratio of the distance between the intersections and the vehicle speed. For case 1, the ratio is equal to the cycle length, and the offset between the intersections is zero. For cases 2 through 4, L/V is equal to half the cycle length; the offset is also equal to half the cycle length.

Table 2

Case	L (ft)	C (sec)	V (mi/hr)	V (ft/sec)	L/V
1	1650	45	25	36.75	45
2	600	32.8	25	36.75	16.4
3	2050	80	35	51.5	40
4	4000	100	55	80.9	50

Case 1 is an example of a simultaneous system, in which the signal displays always change to green at the same time at all of the intersections in the system, and in both directions at each intersection in the system. Cases 2 through 4 are examples of a single alternate system, in which the displays at every other intersection change to green simultaneously, while the offsets at adjacent intersections are equal to one half the cycle length. These relationships can be written as follows:

For simultaneous system

$$C = \frac{L}{V}$$

$$O = 0 = C$$

For single alternate system

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

$$O = 0.5C$$

where:

C = cycle length, sec
L = distance between intersections, ft
V = vehicle speed, ft/sec

Activity 3 (Discovery): Two-Way Progression in Downtown Areas

In the previous section, you made observations about the relationship between cycle length, speed, and intersection spacing necessary to achieve two way coordination. You considered both simultaneous and single alternate systems, where the cycle length is the ratio of the intersection spacing L and the vehicle speed V

$$C = \frac{nL}{V}$$

and where n = 1 for simultaneous systems and n = 2 for single alternate systems.

In this section, you will explore some of the opportunities for two-way coordination in a downtown area where block spacing is short and speeds are relatively low, and along an urban arterial with both longer signal spacing and higher vehicles speeds.

In many downtown areas in the U.S., the block length (and thus the spacing between signalized intersections) ranges from 250 ft and 800 ft. Travel speeds vary but it is not uncommon to observe speeds between 10 and 20 mi/hr. So, what are the conditions in which two-way coordination is possible along one downtown street, and how might we approach finding out the answer to this question?

First, let's look at a matrix of intersection spacing and vehicle speed, with the cycle length that results for each pair of values of spacing and speed, using the equations above. Table 3a shows the results for a simultaneous system while Table 3b shows the results for a single alternate system. For example, when the intersection spacing is 400 feet and the vehicle speed is 15 mi/hr, the cycle length that produces two way progression for a simultaneous system is 18.2 sec. For a single alternate system, the resulting cycle length is 36.4 sec.

Table 3

a. Simultaneous System

	Vehicle speed, mi/hr		
Intersection spacing, ft	**10**	**15**	**20**
250	17.0	11.4	8.5
300	20.5	13.6	10.2
350	23.9	15.9	11.9
400	27.3	18.2	13.6
450	30.7	20.5	15.3
500	34.1	22.7	17.0
550	37.5	25.0	18.8
600	40.9	27.3	20.5
650	44.3	29.5	22.2
700	47.7	31.8	23.9
750	51.1	34.1	25.6
800	54.5	36.4	27.3

b. Single Alternate System

	Vehicle speed, mi/hr		
Intersection spacing, ft	**10**	**15**	**20**
250	34.1	22.7	17.0
300	40.9	27.3	20.5
350	47.7	31.8	23.9
400	54.5	36.4	27.3
450	61.4	40.9	30.7
500	68.2	45.5	34.1
550	75.0	50.0	37.5
600	81.8	54.5	40.9
650	88.6	59.1	44.3
700	95.5	63.6	47.7
750	102.3	68.2	51.1
800	109.1	72.7	54.5

While both cycle lengths produce two way progression, they wouldn't be practical to implement in the field. Why? Both cycle lengths are too short. There are a number of other combinations that would never make practical sense. For example, we will never see the very short cycle length that would result from a 250 ft intersection spacing with 20 mi/hr speeds operating with a simultaneous system. Neither are we likely to see, in a downtown area, a cycle length of nearly 110 seconds that would result from 800 ft intersection spacing, 10 mi/hr travel speeds, with a single alternate system.

A reasonable constraint for cycle lengths in downtown areas is a range of 50 to 80 sec. If this boundary condition is imposed, in addition to those for intersection spacing and vehicle speed already described, the following practical combinations result (see Table 4).

Table 4

a. Simultaneous System

	Vehicle speed, mi/hr		
Intersection spacing, ft	**10**	**15**	**20**
250			
300			
350			
400			
450			
500			
550			
600			
650			
700			
750	51.1		
800	54.5		

b. Single Alternate System

	Vehicle speed, mi/hr		
Intersection spacing, ft	**10**	**15**	**20**
250			
300			
350			
400	54.5		
450	61.4		
500	68.2		
550	75.0	50.0	
600		54.5	
650		59.1	
700		63.6	
750		68.2	51.1
800		72.7	54.5

We can also show this as more of a continuous band of vehicle speeds for signal spacings between 400 ft and 800 ft (see Figure 6). Note that even though some downtown areas have block spacings as low as 250 ft, there are no practical combinations of cycle length, speed, and spacing for distances below 400 ft for two-way operation.

Suppose that our block spacing is 500 ft. Using data from Figure 6, we can produce practical cycle lengths of 68 sec, 57 sec, and 49 sec with vehicle speeds of 10, 12, and 14 mi/hr, respectively.

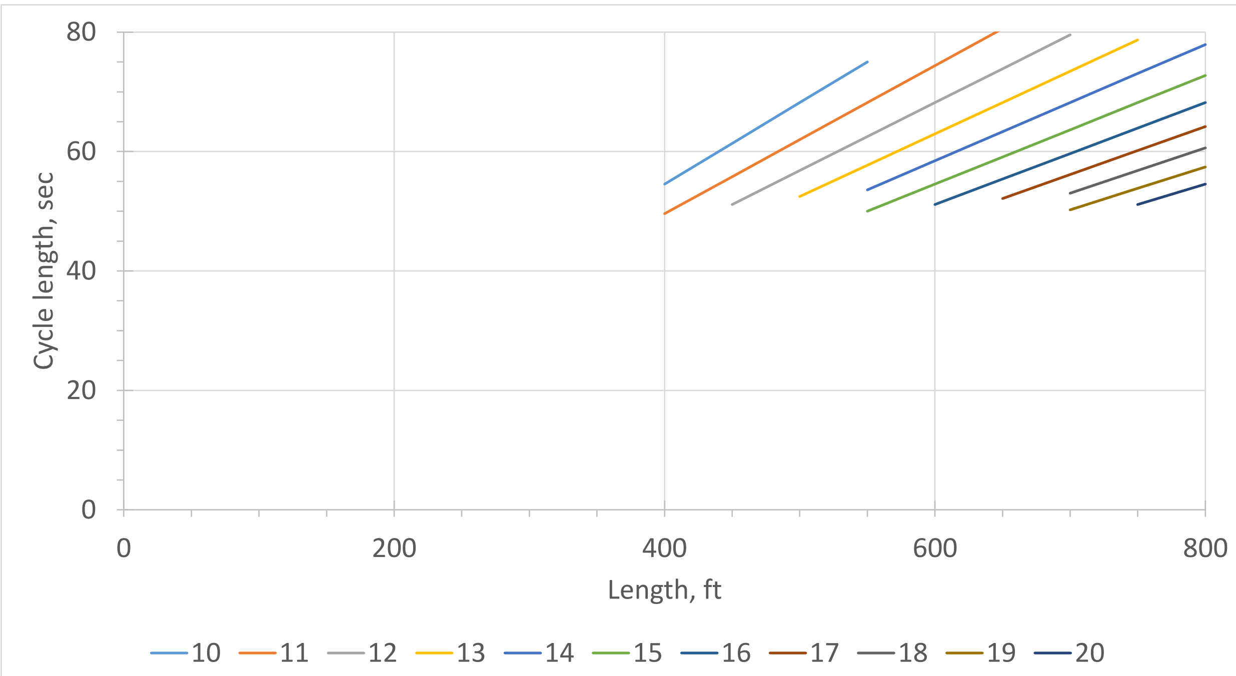


Figure 6

Activity 5 (Recap)

Let's summarize the relationships that we've discovered between cycle length, intersection spacing, and vehicle speed and provide some additional generalization. In general, to achieve progression in both directions, sometimes called a resonant cycle length, the following relationships apply.

$$C = \frac{nL}{V}$$

where the variables are defined as above, and

- n = 1 for simultaneous systems
- n = 2 for single alternate systems
- n = 4 for double alternate systems, (define).

There are other possible combinations that produce resonant cycles as follows:

Simultaneous systems

$$C = \frac{L}{mV} \;, m = 1, 2, 3, 4, \dots$$

Single alternate systems

$$C = \frac{2L}{mV}, m = 1, 3, 5, 7, \dots$$

Double alternate systems

$$C = \frac{4L}{mV}, m = 1, 5, 9, 13, \dots$$

Activity 6 (Example): Limitations, Practical Options, and Goals (Two-Way Operation)

For conditions found in most traffic control systems along urban arterials, trade-offs must be considered. Offsets that provide good progression in one direction, result in poor progression or limited progression opportunities in the other direction. Rarely do we see the combination of C, L, and V illustrated earlier. Thus we need to make a choice of providing good progression in one direction, for one set of movements, at the expense of other movements. We will consider one case to illustrate these points. For this case, you will explore options that provide varying degrees of progression in both directions of an arterial.

This example consists of five signalized intersections in Coeur d'Alene, Idaho, with spacing between the intersections ranging from 448 feet to 2323 feet. The U.S. 95 corridor through Coeur d'Alene is often congested with a mix of commuter, commercial, and recreational travel. While there are a number of vehicles desiring to travel through all five intersections, there is also a substantial volume of turning traffic to and from the side streets, which serve several major commercial areas and employment centers. The average travel speed along the corridor is 35 miles per hour. The cycle length is 100 sec and the green time is evenly split between the main street and the side streets. Table 5 shows the relevant data about the corridor.

Table 5

Intersection	Distance (ft)	Green (sec)	Offset (sec)	Platoon width (sec)	Speed (mi/hr)	Speed (ft/sec)	Travel Time (sec)
Ironwood		50	0	50			
	1367				35	51.3	26.6
I90W		50	26.6				
	566				35	51.3	11.0
I90E		50	37.6				
	448				35	51.3	8.7
Appleway		50	46.3				
	2323				35	51.3	45.3
Neider		50	91.4				

The most obvious characteristic about the corridor, in the context of the discussion earlier in this chapter, is the irregular spacing between the signalized intersections. This means that the theory for simultaneous or single alternate systems doesn't apply in this example. So, what quality of progression is possible under these conditions and what tradeoffs must be made to achieve the highest degree of coordination for at least some of the movements traveling through the corridor?

We will first consider one way progression only, first in one direction and then in the other direction. One way progression is based only on the travel time between the intersections.

Here are some questions to consider:

- What should the offsets be to achieve coordination in the northbound direction? In the southbound direction? Both directions?
- Should other cycle lengths be considered?

Activity C03

Purpose
The purpose of this activity is to use the spreadsheet that you constructed in AC02 to identify signal timing options to achieve good progression along your arterial system.

Tasks

1. Change the distances and speeds in your time-space diagram spreadsheet tool to conform to the data in your VISSIM network.
2. Find the optimal offsets for the following cases based on the travel times between intersections, using the base conditions of a 100 sec cycle length and even green splits.
    a. The up direction only
    b. The down direction only
3. Using the same base conditions as in task 2, experiment with different offset combinations to find the best progression in both directions. Document your two "best" solutions.
4. Change the cycle length to 60 secs and maintain even green splits. Find the two offset combinations that yield the "best" two-way progression.
5. Prepare one slide in PowerPoint that shows your recommended signal timing for two-way operation using a cycle length of 100 sec.

Critical Thinking Questions

1. Describe the results of the signal coordination analysis from task 2 where you considered only one-way progression.
2. Describe the results of the signal coordination analysis from task 3, where you considered two-way progression. Is progression possible in both directions? Why or why not?
3. Considering the results from task 3, what opportunities and limitations for progression do you envision for your design project?
4. Discuss what goal you might set for your design project based on your answer to question 3.
5. How will a queue that is still clearing at the downstream intersection affect the offset to achieve progression for an arriving platoon?
6. Does the change in cycle length from 100 sec to 60 sec affect your progression results? What is the change in the bandwidth when this cycle length change is made?

Deliverable

1. Excel spreadsheet with your time space diagrams and results from tasks 1, 2, 3, and 4.
2. Word document with answers to the critical thinking questions.
3. AC03 should be uploaded to BBL by Thursday at 800 am. You should also have both documents available for class on Thursday.
4. PowerPoint slide available to show in class on Thursday.