ACTIVITY

13 Phasing, Rings, and Barriers

READING

Purpose

This activity will give you the opportunity to learn how movements and phases are safely sequenced.

Learning Objective

- Describe NEMA phasing and the concept of rings and barriers
- List the NEMA ring operational rules

Deliverables

- Define the terms and variables in the Glossary
- Prepare a document that includes answers to the Critical Thinking Questions

Glossary

Provide a definition for each of the following terms and variables. Paraphrasing a formal definition (as provided by your text, instructor, or another resource) demonstrates that you understand the meaning of the term or phrase.

concurrency group	
movement	
NEMA phase numbering	
overlap	
phase	
ring	
ring barrier diagram	

Critical Thinking Questions

When you have completed the reading, prepare answers to the following questions.

1. What is the purpose of the ring barrier diagram?

2. How is timing represented in a ring barrier diagram?

3. Why use a ring barrier diagram instead of a conflict matrix to describe the sequencing of phases?

4. What is the difference between a *movement* and a *phase*?

Information

Separating and Sequencing Movements

The primary function of a traffic signal is to safely separate and sequence the movement of vehicles traveling through an intersection so as to minimize the probability of crashes and to maximize the flow of vehicles. The "separation" of movements in time is accomplished by inserting the change and clearance timing intervals (displayed to the vehicle user as yellow and red clearance indications) between conflicting movements. The change and clearance intervals will be discussed later in this book, in Chapter 9. The "sequencing" of vehicle movements is the subject of this current chapter.

The sequencing of movements is accomplished through the sequencing of displays or indications to which users respond. The four-component traffic control process model, introduced in Chapter 1 and shown in Figure 48, shows the interdependencies of the user, the detector, the controller, and the display at a conceptual level. Here the dependence of the user on the display is clear: the user responds in a safe and appropriate way to the information conveyed in the display. But if we take a closer look at the actual hardware used in the field, we can better see the detector-controller-display linkages as well.

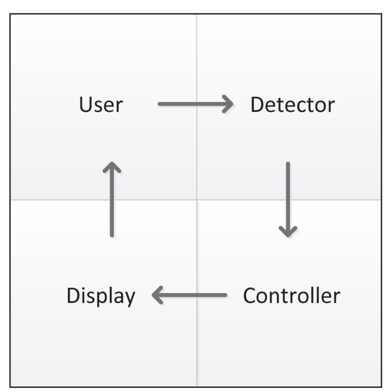


Figure 48. Traffic control process model

The Cabinet

The controller is housed in a box called the cabinet, which is located at the intersection. See Figure 49. Modern cabinets have 16 detector amplifiers, a controller that can accommodate up to 16 phases and 4 rings, and 16 load switches. Figure 50 shows an example of the location of the detector amplifiers, the controller, and the load switches inside a cabinet.

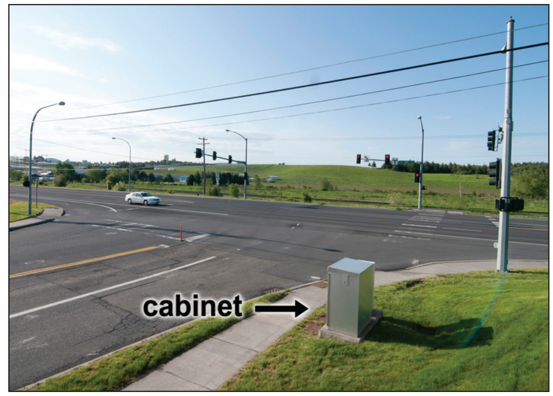


Figure 49. Cabinet at intersection

- A detector amplifier accepts calls from one or more loop detectors; each loop detector monitors traffic on one or more lanes. Each loop sets up an inductance field which is used to sense vehicles and generates an output signal to the traffic controller. The sensitivity of the loop is based on how well the metal interrupts the inductance field and the sensitivity of the amplifier settings that is needed to generate an output. The output signal from the amplifier effectively closes the detection circuit to the controller.
- The controller interprets this signal (on or off) as either a call or no call. The call is registered when an algorithm in the controller has processed the input.
- The controller provides the logic for determining when and how long each phase will time, based on the calls received from the detectors and the timing plan that has been programmed. A phase is a timing unit that controls the operation of one or more movements. One phase generally drives one load switch, although through the use of overlaps it can drive multiple outputs (load switches). Overlaps can also combine phases to meet special needs.
- Based on outputs from the controller, the load switches drive the displays that users respond to by converting the low voltage controller output to a higher voltage that drives the traffic signal display. Each display typically has up to three indications, the maximum number of indications driven by a load switch. The indications include a “go” indication that indicates that a user has the right-of-way and can safely proceed through the intersection and a “stop” indication that tells the user not to enter the intersection.

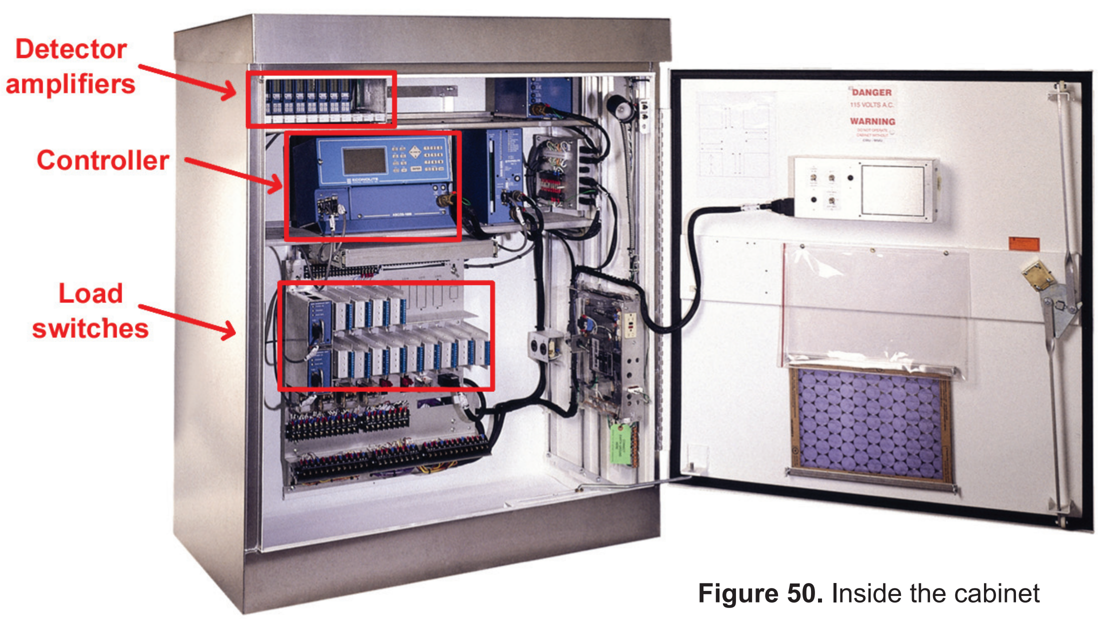


Figure 50. Inside the cabinet

Movements and Phases

Two of the concepts introduced in the previous section, the movement and the phase, are often used interchangeably (incorrectly so), but are distinct and mean different things. Let's start with the term "movement." We will define a movement as the response of the user to a "go" indication. This response has two attributes: the compass direction from which the user originates and the turn which the user makes. The compass direction normally includes one of the following designations: eastbound, westbound, northbound, or southbound. The turn designation includes left turn, through, or right turn.

We can also say whether a movement is opposed or not by another movement by using the terms protected, permitted, or not opposed. A protected movement has the unambiguous right-of-way, while a permitted movement may continue through the intersection only when there is a large enough (and safe) gap in the opposing traffic movement.

Movements are commonly numbered as shown in Figure 51. Left turn movements are designated with odd numbers (1, 3, 5, and 7) and through movements are designated as even numbers (2, 4, 6, and 8). While right turn movements are often given the same number as their compatible through movements, they are sometimes given the same right digit with a leading "1."

A phase is a timing unit that controls one or more movements. The timing unit includes three timing intervals, one each for the indications of green, yellow, and red. Phases are typically numbered in the same way as movements, with the exception that the even numbered phases normally control both the through and right-turn movements. Figure 52 shows the standard NEMA phasing convention (so-named since the National Electrical Manufacturers Association has established standards for the operation of an actuated traffic controller). For consistency, phases 2 and 6 should correspond to the through movements on the major street, while phases 4 and 8 should correspond to the through movements on the minor street. Similarly, phases 1 and 5 should correspond to the left turning movements on the major street and phases 3 and 7 should correspond to the left turning movements on the minor street.

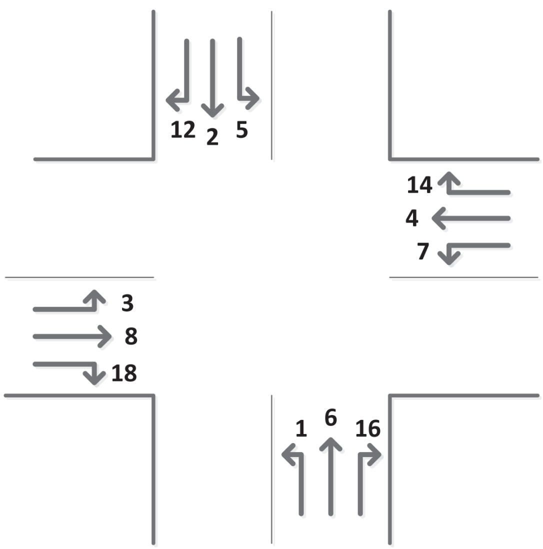


Figure 51. Movement numbers

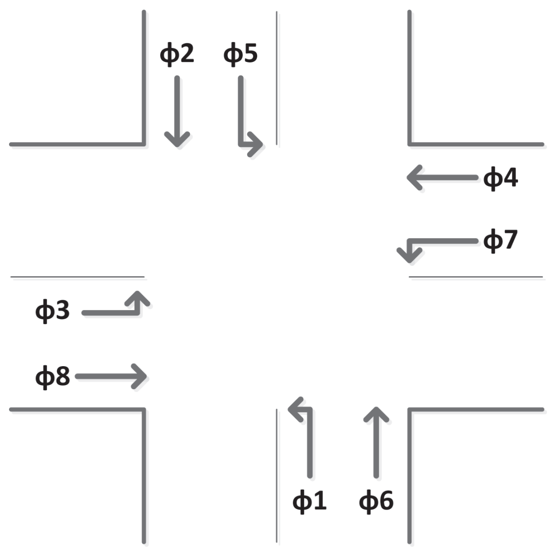


Figure 52. NEMA phase numbers

The Conflict Matrix

The conflict matrix defines the phases that are compatible and can time concurrently. It also defines phases that are not compatible and thus cannot time concurrently. The safety task of preventing non-compatible phases from timing concurrently is managed by the malfunction monitoring unit (MMU) . The MMU monitors load switch outputs and ensures that conflicting green indications are not displayed at the same time.

For example, suppose that the phase 1 display indicates green. Either phase 5 or phase 6 can also display green concurrently with phase 1 green as shown in Figure 53 and Figure 54. This means that either movements 1 and 5 or movements 1 and 6 can be served concurrently.

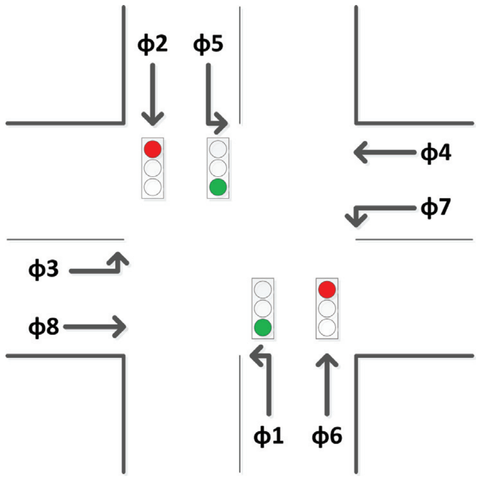


Figure 53. Phase 1 green and phase 5 green can be displayed concurrently

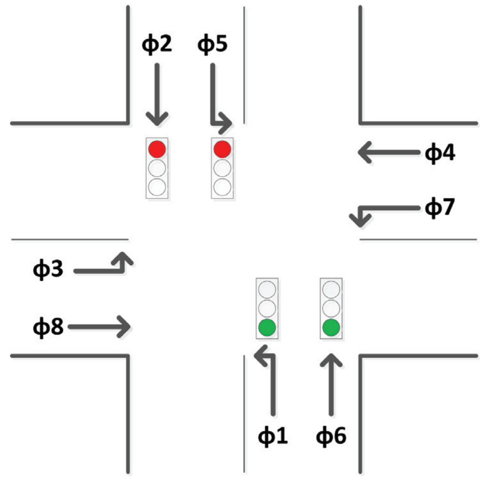


Figure 54. Phase 1 green and phase 6 green can be displayed concurrently

Figure 55 shows the phases that are both compatible with and in conflict with phase 1 in the form of a conflict matrix. Phases that conflict with phase 1 (phases 2, 3, 4, 7, and 8) are marked with an "X" in the column under Subject Phase 1. The empty squares next to phases 5 and 6 indicate that they are compatible with phase 1.

Compatible or Conflicting Phases	Subject Phase 1	2	3	4	5	6	7	8
1								
2	X							
3	X							
4	X							
5								
6								
7	X							
8	X							

Figure 55. Conflict Matrix showing conflicting and compatible phases for phase 1

Compatible or Conflicting Phases	Subject Phase 1	2	3	4	5	6	7	8
1		X	X	X			X	X
2	X		X	X			X	X
3	X	X		X	X	X		
4	X	X	X		X	X		
5			X	X		X	X	X
6			X	X	X		X	X
7	X	X			X	X		X
8	X	X			X	X	X	

Figure 56. Example conflict matrix

Now let's fill in the Conflict Matrix for all phases at a standard four leg intersection, as shown in Figure 56. Considering each subject phase in turn, the empty squares in each column show the phase pairs that are compatible, in which the movements controlled by these phases can move at the same time. The "X" squares show incompatible phases, in which the movements controlled by these phases cannot operate at the same time. The conflict matrix will be the basis for constructing a ring barrier diagram, which we will do in the next section of this reading.

Ring Barrier Diagram

The ring barrier diagram specifies the safe sequencing of phases (and thus the movements that they control) at a signalized intersection. We can construct the ring barrier diagram as follows. First, we separate the phases into two “concurrency groups”, one group for the phases controlling the east-west movements and a second group for phases controlling the north-south movements. We separate the concurrency groups by a barrier. Figure 57 shows the beginning structure of the ring barrier diagram.

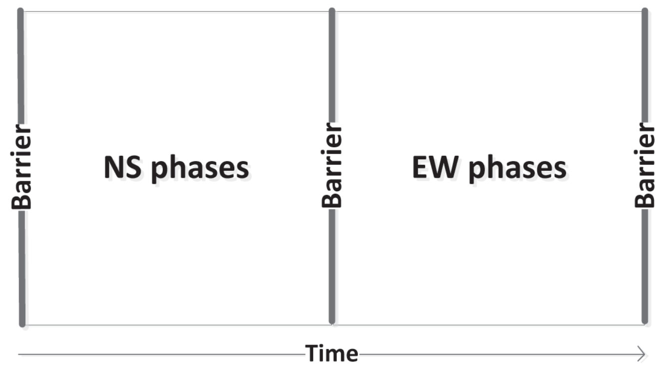


Figure 57. Beginning structure of ring barrier diagram

Next we consider, for the phases in each concurrency group, the order in which the phases must operate or time. We define a ring as a sequence of phases that are not compatible and that must time sequentially. For the north-south concurrency group, the movements controlled by phases 1 and 2 (the northbound left turn and the southbound through) must occur sequentially. Similarly, the southbound left turn and the northbound through movements, controlled by phases 5 and 6, must also occur sequentially. We can note these sequences in an expanded view of the ring barrier diagram (see Figure 58), where we have two rings, one for each sequence. Phases 1 and 2 are placed in ring 1, while phases 5 and 6 are in ring 2. The dashed lines indicate that the movement is “permitted.” Here movements 12 and 16 are right turns (permitted) that must yield to pedestrians.

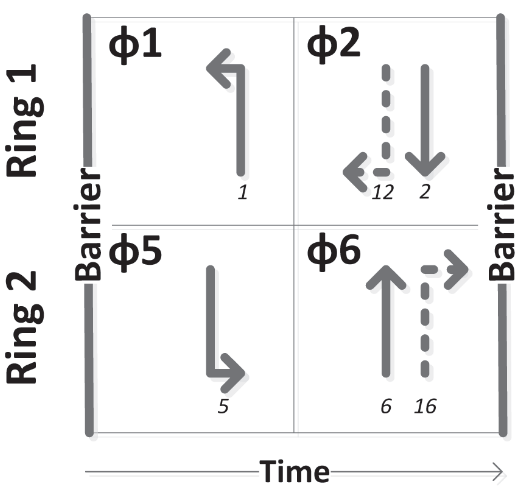


Figure 58. Partial ring barrier diagram for phases controlling EW movements

We are led to two rules that generally describe the standard ring barrier diagram:

1. The phases in a ring must be served sequentially and cannot be served concurrently because they are not compatible with each other.
2. A phase in one ring may be served concurrently with phases in the other ring in the same concurrency group.

A complete ring barrier diagram for the phases that control the east-west and north-south movements is shown in Figure 59. Similar to the north-south movements, the east-west movements are controlled in two rings or sequences: phase 4 follows phase 3 in ring 1, and phase 8 follows phase 7 in ring 2. Overall, ring 1 includes phases 1, 2, 3, and 4, while ring 2 includes phases 5, 6, 7, and 8.

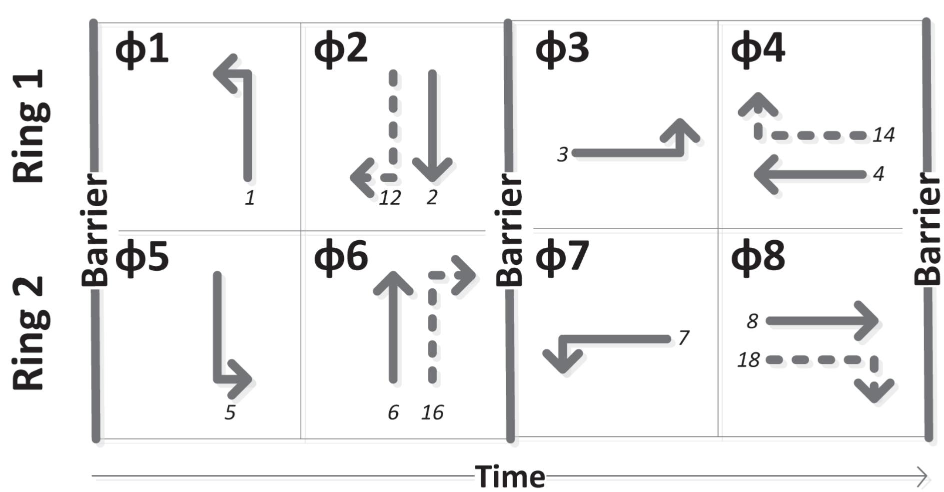


Figure 59. Complete ring barrier diagram

This depiction of the sequencing of the eight phases is now complete. However, there is an important feature of this sequencing that provides for more efficient operation when the timing of the phases is tied to the level of demand for each movement during a given signal cycle, as occurs with actuated signal control. Suppose, for example, that phase 1 times for 10 seconds, while the demand for the movement served by phase 5 requires 20 seconds to be served. We can represent this timing pattern in a partial ring barrier diagram as shown in Figure 60.

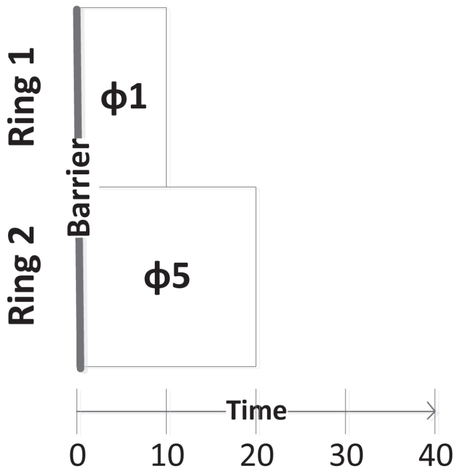


Figure 60. Partial ring barrier diagram showing phases 1 and 5

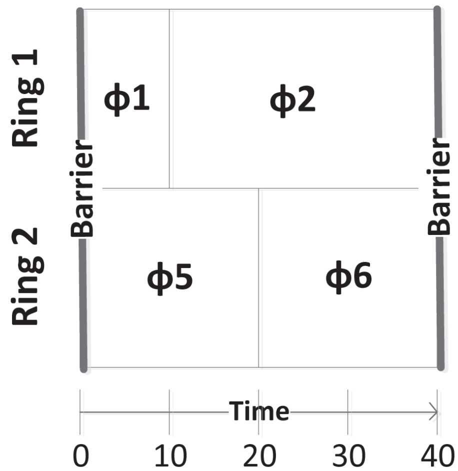


Figure 61. Example partial ring barrier diagram for north-south concurrency group

When phase 1 ends, phase 2 can begin timing since it can run concurrently with phase 5. If phase 2 then times for 30 seconds, and phase 6 times for 20 seconds, we can represent the partial ring barrier diagram for the phases serving the north-south movements as shown in Figure 61. Note that both rings 1 and 2 must "cross the barrier" at the same time, meaning that the active phases in these rings (in this case, phases 2 and 6) must end at the same time.

Consider another situation in which the demand for phase 1 requires 15 seconds, while the demand for phase 5 requires 10 seconds. Figure 62 shows the partial ring barrier diagram for this condition.

Now, what if the demand for phases 2 and 6 each requires 25 seconds to serve? What does the ring barrier diagram look like? Even though phase 6 requires 25 seconds, it will actually time for 30 seconds (with five seconds of slack time, or time that is not needed to service vehicle demand) because phase 2 and 6 must cross the barrier at the same time, as shown in Figure 63. During this "slack time" period, phase 6 is not timing but "resting in green."

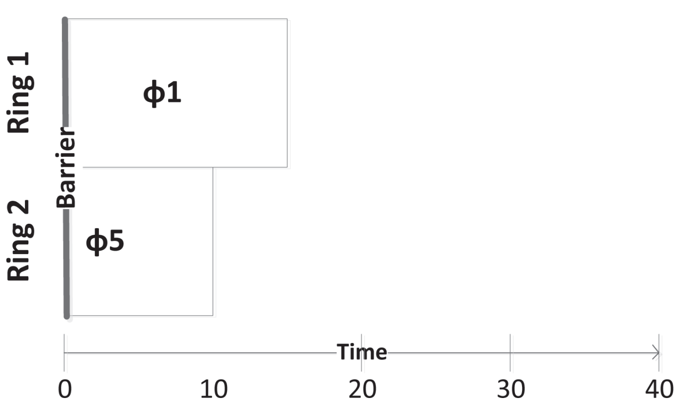


Figure 62. Example partial ring barrier diagram for north-south concurrency group

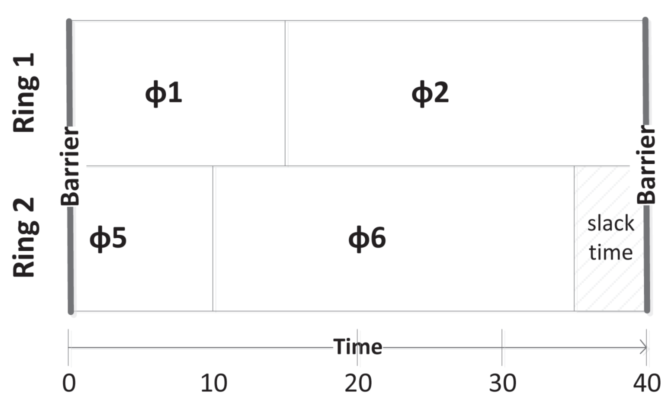


Figure 63. Example partial ring barrier diagram for north-south concurrency group with slack time

Other Issues

Phasing is a complex topic, and this reading covers only some of the basic concepts related to phasing. However, it is worth mentioning four other topics, including left turn phasing, split phasing, single ring operations and overlaps, and phasing for T-intersections.

Left turns

The previous discussion assumed leading protected left turns for the phasing sequence. This means that left turn movements are served first, before the compatible through movements, and that the left turn movements are protected. It is also common for left turns to be permitted, in which case left turning drivers must wait for a safe gap in the opposing traffic stream to complete their maneuver. An example ring barrier diagram for permitted left turn phasing is shown in Figure 64. Here all six movements in the north-south concurrency group are served at the same time by phases 2 and 6, while phases 4 and 8 simultaneously serve the six movements in the east-west concurrency group. The left turn movements (1, 3, 5, and 7) are shown as a dashed line since they are permitted and must yield to opposing through traffic. Various left turn phasing options will be discussed in more detail in Chapter 8 of this book.

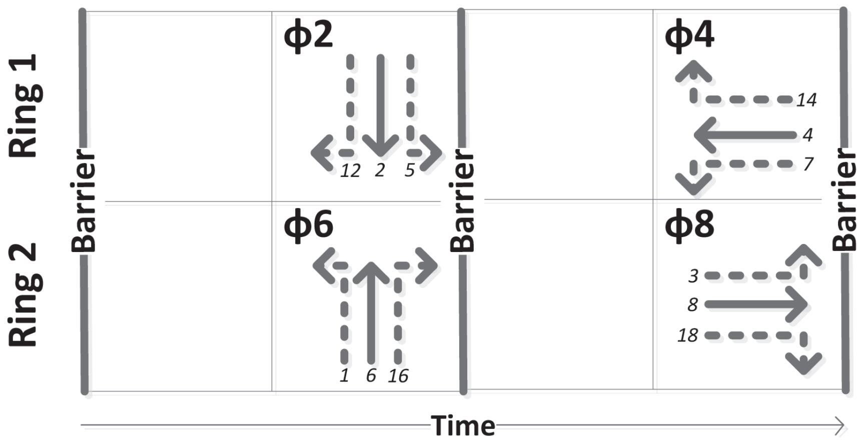


Figure 64. Ring barrier diagram for permitted left turn phasing

Split Phasing

Another phasing scheme is called split phasing. Split phasing is when each of the four intersection approaches is served in turn, sequentially, as shown in the ring barrier diagram in Figure 65. Split phasing is often used when the intersection geometrics limit opposing left turn movements from traveling at the same time. Split phasing can be accomplished with a single ring, a concept that will be discussed further in the next section.

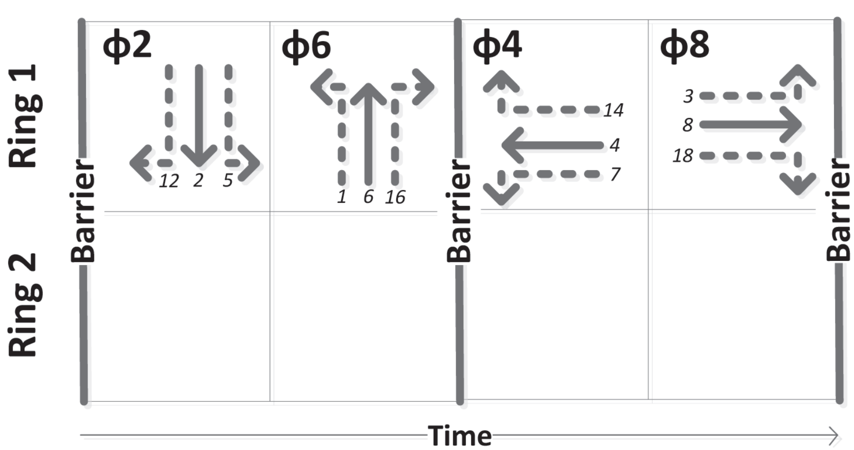


Figure 65. Ring barrier diagram for split phasing

Single Ring Operation and Overlaps

While two, or dual, ring operation is common, it is sometimes feasible for a single ring operation to be used. Consider the movement diagram shown in Figure 66. While this is a non-standard intersection (only three approaches with non-90 degree legs), it is not uncommon to find designs that are similarly unusual. One method of phase sequencing for this intersection is to have three phases: 8, 6, and 7. These phases would control movements 3 and 8, movements 6 and 16, and movement 7, respectively, as shown in Figure 67. Because the geometry of the intersection allows movement 18 to operate at the same time as movements 3 and 8 and movements 6 and 16, movement 18 can be controlled by an overlap, or sometimes called a child phase (overlap A) to the parent phase (phases 8 and 6). And, because movement 14 can operate compatibly with all of the vehicle movements, it can be operated as overlap B, with parent phases 8, 6, and 7.

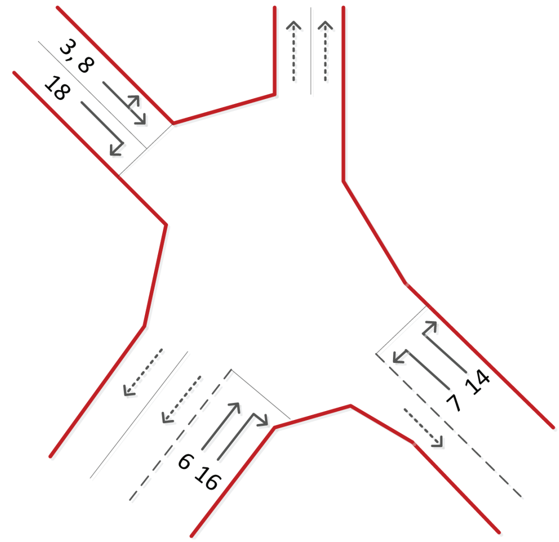


Figure 66. Movement diagram

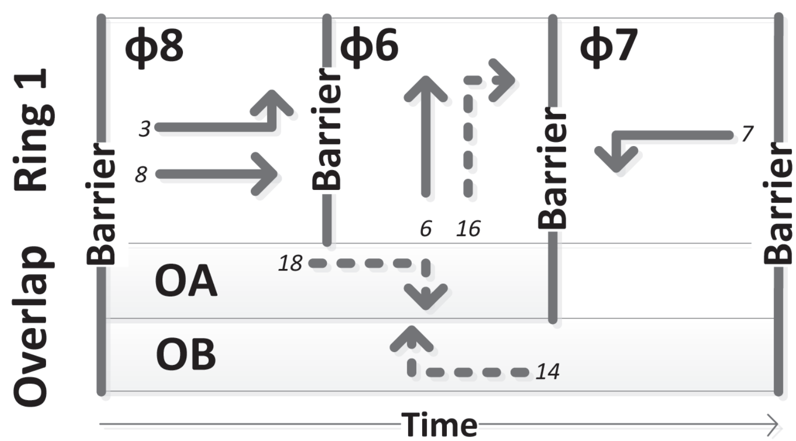
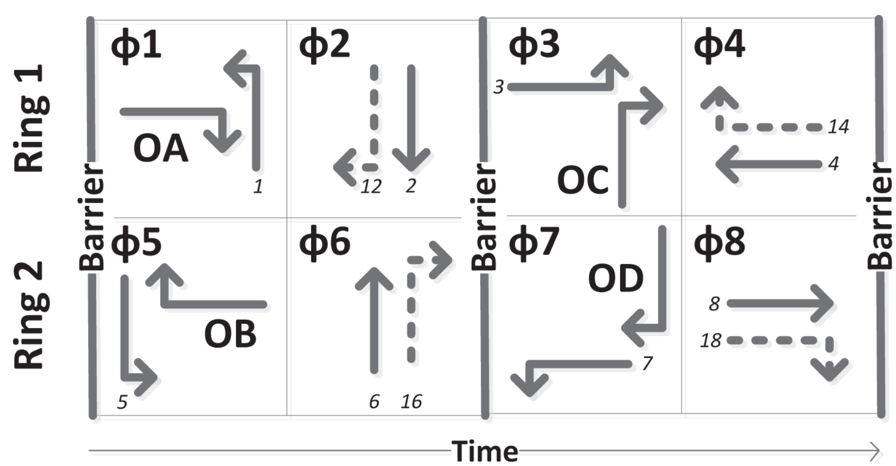


Figure 67. Ring barrier diagram for single ring and overlaps

A more standard overlap operation is shown in Figure 68. Here, the overlaps are each right turns that shadow what might be generally thought of as a conflicting left turn movement. For example, overlap A would "shadow" the parent phase 1. Standard cabinets can accommodate up to four overlaps, each one driving a load switch, which in turn drives a display and the included indications.

Figure 68. Overlaps



Phasing for T-Intersections

Suppose we had to develop a phasing plan for a T-intersection, in which there are only six movements, and not the twelve movements that are present at the standard four-leg intersection. The movement diagram is shown in Figure 69, while the phases that would control these movements are shown in the diagram in Figure 70. The ring barrier diagram is shown in Figure 71.

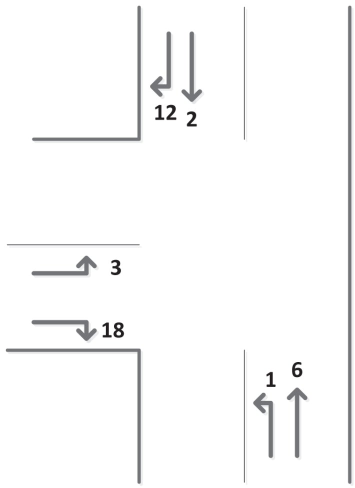


Figure 69. Movement diagram for T-intersection

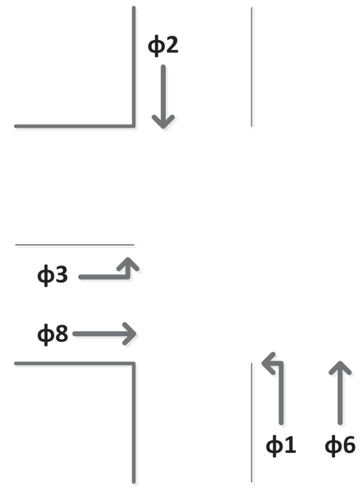


Figure 70. Phase diagram for T-intersection

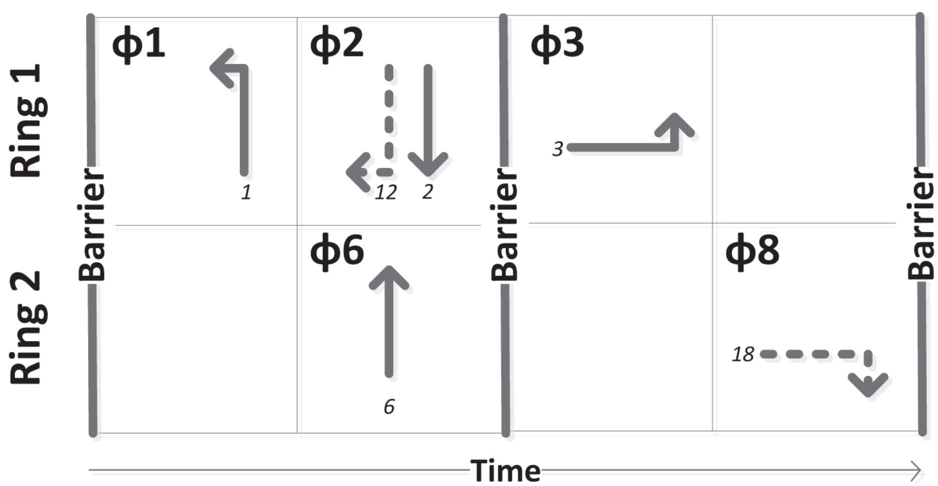


Figure 71. Ring barrier diagram for T-intersection