How Traffic Control Signals Work*

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Abstract

Traffic control signals allow vehicles and pedestrians to move through intersections safely and efficiently. Here is how they work.

Keywords: traffic control signals; traffic intersections; traffic.

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1 Introduction

At a traffic intersection vehicles and pedestrians must cross each other's path. To allow this to happen safely, a traffic control signal is used to delay traffic in one direction while it proceeds in another. To maximize efficiency, the traffic control signal lets traffic flow when there is a long line of vehicles and allows multiple traffic flows provided they do not intersect. However, making a vehicle wait too long compromises safety, since a vehicle operator will consider an excessive delay as an indication that the traffic control signal is not working, and proceed into the intersection in spite of it.

In the United States, the standard for traffic control devices is the Manual on Uniform Traffic Control Devices, known as MUTCD[1]. Much of the terminology and some of the illustrations in this paper were taken from that document.

2 Example 01: Single-lane Bridge

To describe how traffic control signals work we begin with a simple example: a single-lane bridge:

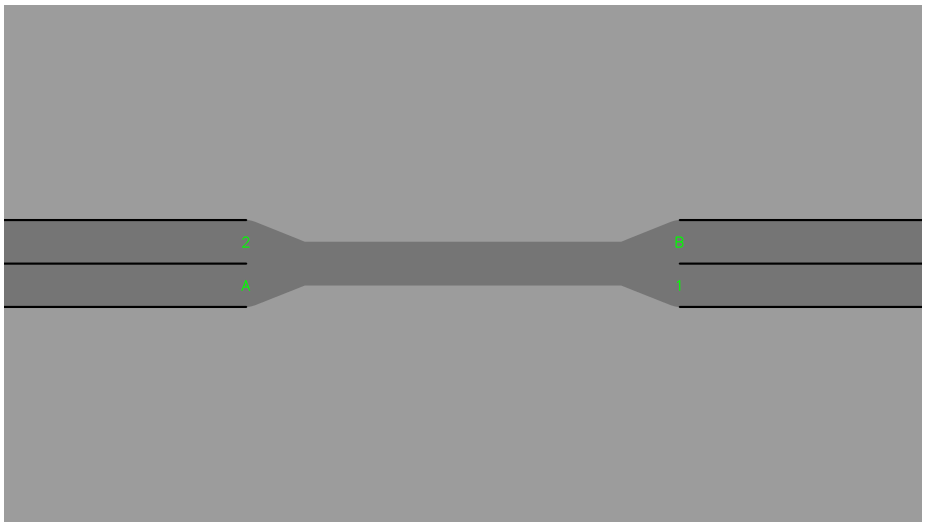


Figure 1: Example 01: single-lane bridge

In figure 1 vehicles approach from the west on lane A. From there they can cross the bridge and exit on lane 1, or make a U-turn and exit on lane 2. Similarly, vehicles approach from the east on lane B and either cross the bridge, exiting on lane 2, or make a U-turn and exit on lane 1.

2.1 Conflicts

We need to examine the intersection to see where, when traffic is moving in one way, it must not be permitted to move in another way. We call each way that vehicles can move a travel path, and each travel path is named for the entering and exiting lane. Here we have travel paths A1, A2, B1, and B2. The two U-turns, A2 and B1, do not interfere with each other, but all the others do since they place two vehicles in the same place at the same time.

When a vehicle reaches the bridge on lane A or B we do not know which lane it intends to exit on, so we must block all travel paths which conflict with any travel path starting at that lane. Thus, lane A must be blocked when a vehicle has entered the bridge from lane B, and vice-versa.

This analysis is simple for the one-lane bridge but it is more complex for complex intersections.

2.2 Signal Faces

In order to allow vehicles to cross the bridge safely, we need signal faces on lanes A and B to stop traffic from entering the bridge if traffic is moving the other way.

A signal face looks like this:

Figure 2: signal face with three circular lamps

Vehicle operators know that if the red lamp is lit they may not enter the intersection. The green lamp allows the vehicle to proceed, and the yellow lamp gives warning that the red lamp is about to light.

For maximum efficiency, whenever possible a vehicle approaching a signal face should see a green light so it doesn't have to stop or even slow down as it crosses the bridge. To make this work from both directions we need to keep both signal faces red until a vehicle approaches, then turn that lane's signal face green.

2.3 Sensors

In order to know when we need to stop traffic from entering the bridge we have sensors in the lanes to detect vehicles. When a vehicle is detected by a sensor we describe the sensor as being triggered.

2.3.1 Traffic Present

Lanes A and B each have a vehicle sensor at the stop line where the lane meets the intersection. This sensor tells us that a vehicle is entering the intersection or is waiting to enter. We call this the Traffic Present sensor.

2.3.2 Traffic Approaching

For safety reasons the Traffic Present sensor isn't sufficient. Because bridge traffic is very light, vehicle operators will be used to seeing the signal face turn green when they reach the intersection, and when it doesn't they will be unable to stop before entering the bridge. To solve this problem we need a second vehicle sensor set back from the Traffic Present sensor. This lets us turn the signal face green before the vehicle is close to the intersection. If the vehicle operator does not see the green light when he is used to seeing it he will have time to stop safely. We call this the Traffic Approaching sensor.

2.4 Timers

In addition to signal faces and their associated sensors, the traffic control signal needs a sense of time. Here are the most important timers associated with each signal face:

2.4.1 Red Clearance Time

The Red Clearance time is the time between when a signal face turns red and the last vehicle to enter the bridge from that lane has left the bridge, so that we can give the other lane a green light.

2.4.2 Yellow Change Time

To give traffic warning that we are soon turning red, we first turn the light yellow for Yellow Change time.

2.4.3 Minimum Green Time

When a signal face turns green we give the traffic this much time to get moving before we consider turning red.

2.4.4 Passage Time

When a vehicle operator sees a signal face turn yellow, he must stop before entering the intersection if he can do so safely, or proceed through the intersection if he cannot. This decision is easy to make if the vehicle is close to the intersection or far from it, but it hard to make in an intermediate situation. To avoid this, we try to turn yellow only when there are no vehicles in this intermediate situation.

We do this by monitoring the Traffic Approaching sensor. If no vehicle has activated this sensor for Passage Time seconds, we can be sure that any vehicles

are either so close to the intersection that they can safely make it through before the signal face turns red, or far enough away that they clearly cannot.

2.4.5 Maximum Green time

If we have reached maximum green time and there has been no conflicting traffic, wait for some conflicting traffic, then look again for a gap.

2.4.6 Maximum Green Extra time

If we have reached maximum green time and there has been no conflicting traffic, but conflicting traffic arrives later, wait maximum green extra time for a gap. If there isn't one, turn red anyway.

2.4.7 Traffic Gone Time

If we are green and there is no conflicting traffic, but we have seen no traffic for Traffic Gone seconds, turn red. This is needed to keep both signal faces red when there is no traffic, which is the normal case. Only if the other signal face has been red for Red Clearance seconds can we give an instant green when traffic approaches.

2.4.8 Green Limit Time

If we have been green for Green Limit seconds, turn red even if there is no conflicting traffic and there is traffic through this signal face's lane.

2.4.9 Red Limit Time

If the signal face has been red for this many seconds, turn it green even if there is no traffic.

2.5 Timer Durations

Here are the lengths of time that each timer runs:

Table 1: Timer Durations

Signal Face	Timer	Duration
A	Red Clearance	10.0
A	Yellow Change	5.0
A	Minimum Green	12.0
A	Maximum Green Extra	3.5
A	Traffic Gone	10.0
A	Passage	3.5

Table 1: Timer Durations continued

Signal Face	Timer	Duration
A	Maximum Green	60.0
A	Green Limit	60.0
A	Red Limit	unlimited
B	Red Clearance	10.0
B	Yellow Change	5.0
B	Minimum Green	12.0
B	Maximum Green Extra	3.5
B	Traffic Gone	10.0
B	Passage	3.5
B	Maximum Green	60.0
B	Green Limit	60.0
B	Red Limit	unlimited

2.6 Toggles

When a signal face detects a vehicle approaching it must not turn green if there is a vehicle already on the bridge coming the other way. This means that the signal faces must communicate with each other. They do this with toggles. Toggles are also used to communicate from sensors to their signal faces.

A toggle may be either set (true) or clear (false). Here are the most important toggles:

2.6.1 Traffic Approaching

When the Traffic Approaching sensor has detected a vehicle it sets this toggle. The toggle remains set until it is cleared by the finite state machine, even after the sensor is no longer detecting a vehicle.

2.6.2 Traffic Present

When the Traffic Present sensor has detected a vehicle it sets this toggle. The toggle remains set until it is cleared by the finite state machine, even after the sensor is no longer detecting a vehicle.

2.6.3 Request Green

When we are red but want to turn green we set this toggle.

2.6.4 Green Request Granted

When we see this toggle set we can ask the other signal face to turn red.

2.6.5 Request Partial Clearance

When we have been granted our request to turn green we set the Request Partial Clearance toggle. This causes the Clearance Requested toggle to be set in the other signal face.

2.6.6 Clearance Requested

When the other signal face sees that its Clearance Requested toggle has been set, it turns red.

2.6.7 Cleared

When the other signal face has been red long enough for all of its traffic to have cleared the intersection it sets its Cleared toggle. This causes the Partial Conflicting Paths are Clear toggle to be set in our signal face.

2.6.8 Partial Conflicting Paths are Clear

When we see this toggle set we can change from red to green.

2.6.9 Traffic Flowing

When we have turned green we set this toggle to indicate that we no longer need to turn green. Doing this gives permission to the other signal face to begin the process of turning green, when and if it needs to.

2.7 Wiring the Finite State Machines to the Lamps

Each signal face finite state machine is wired to the signal face lamps that it controls. Table 2 shows wiring between the signal face finite state machines and the lamps in their signal faces.

Table 2: Lamp Wiring

Signal Face	Signal Face Output Name	Actual Lamp Name
A	Steady Circular Red	Steady Circular Red
A	Steady Circular Yellow	Steady Circular Yellow
A	Steady Circular Green	Steady Circular Green
A	Flashing Circular Red	Flashing Circular Red

Table 2: Lamp Wiring continued

Signal Face	Signal Face Output Name	Actual Lamp Name
A	Flashing Circular Yellow	Flashing Circular Yellow
B	Steady Circular Red	Steady Circular Red
B	Steady Circular Yellow	Steady Circular Yellow
B	Steady Circular Green	Steady Circular Green
B	Flashing Circular Red	Flashing Circular Red
B	Flashing Circular Yellow	Flashing Circular Yellow

2.8 Wiring the Finite State Machines to the Sensors

Each signal face finite state machine is wired to the sensors for its lane.

Table 3: Sensor Wiring

Signal Face	Sensor	Toggles
A	Traffic Approaching	Traffic Approaching
A	Traffic Present	Traffic Present
B	Traffic Approaching	Traffic Approaching
B	Traffic Present	Traffic Present

2.9 Process

With these resources we can construct a process which uses them to move traffic safely and efficiently across the bridge. We have two finite state machines, one for each signal face, and some system programs to let them communicate.

2.9.1 Red State

When a signal face is in the red state its light is red. If it has been red for Red Clearance Time seconds it sets the Cleared toggle.

If it sees that the Traffic Approaching toggle is set it sets the Request Green toggle, which will eventually lead to it moving to the green state.

2.9.2 Yellow State

When a signal face is in the yellow state its light is yellow. If it has been yellow for Yellow Change Time seconds it moves to the red state.

2.9.3 Green State

When a signal face is in the green state its light is green. If it sees that the Clearance Requested toggle is set it moves to the yellow state when there is a gap in the traffic, or if too much time passes without a gap.

2.9.4 System Programs

The green request granted system program looks for the Green Request toggle in either signal face, and sets the Green Request Granted toggle. Other system programs mediate the other stages of moving information between the signal faces. These system programs act in a more complex way when the intersection is more complex.

2.10 Illustrations

2.10.1 Idle

When the intersection starts up all toggles are set to false, all timers are set to stopped, and each signal face finite state machine is set to state Red substate Waiting for Clearance.

Each signal face will proceed from state Red substate Waiting for Clearance to substate Travel Path is Clear. Because the Red Limit timers have infinite duration both signal faces will remain red until some traffic appears.

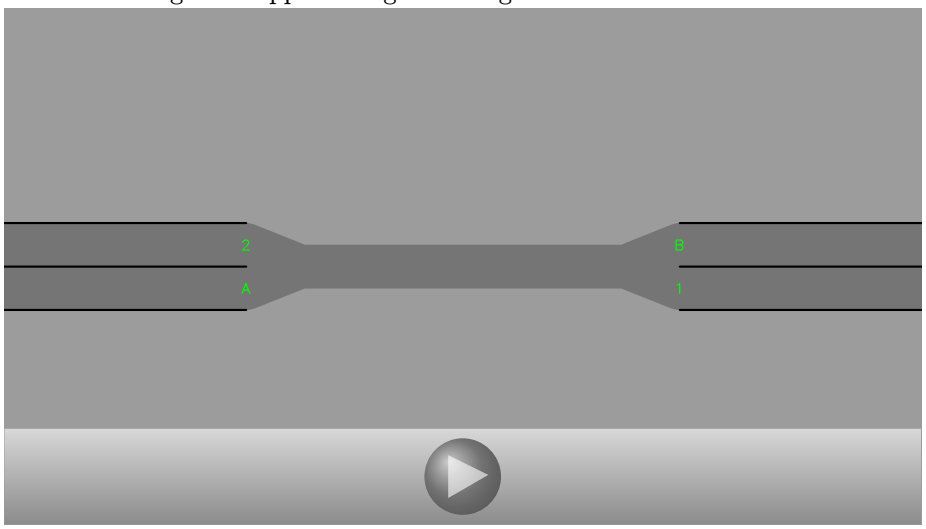
Here is the detailed log:

Table 4: Power On to Idle State, example 01

Time	Lane	Event
000.000	A	Enter state Red substate Waiting for Clearance.
	A	Set lamp to Steady Circular Red.
	A	Start timer Red Clearance.
	B	Enter state Red substate Waiting for Clearance.
	B	Set lamp to Steady Circular Red.
	B	Start timer Red Clearance.
010.000	A	Timer Red Clearance completed.
	B	Timer Red Clearance completed.
	A	Enter state Red substate Travel Path is Clear.
	A	Set toggle Cleared.
	B	Enter state Red substate Travel Path is Clear.
	B	Set toggle Cleared.

2.10.2 Single Car

Consider a single car approaching the bridge from the west.

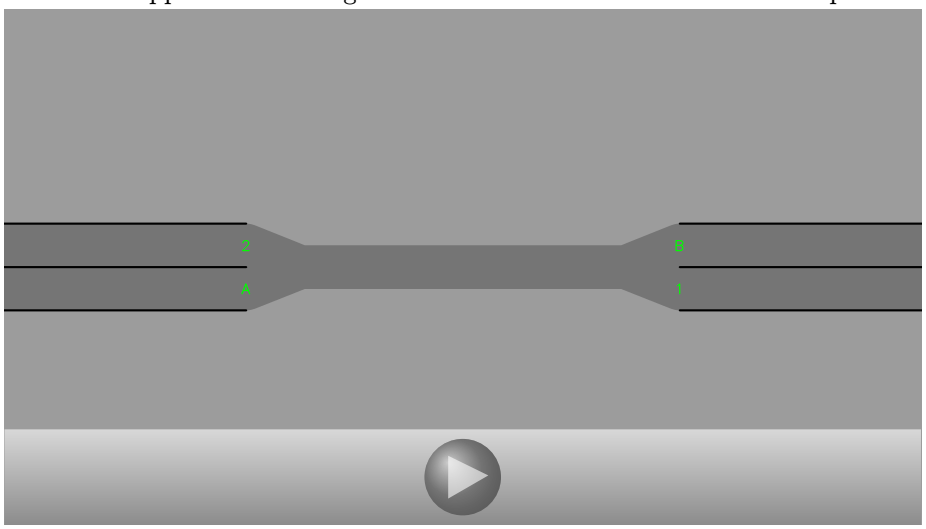


In the above animation, the car coming from the west activates the Traffic Approaching sensor for lane A. The signal face for lane B has been red for some time, so signal face A immediately turns green. The car passes across the bridge without stopping after which signal face A turns red.

If your PDF viewer will not play the animation you can see it on Youtube at this URL: https://youtu.be/YgWkwT_6EcE.

2.10.3 Two Cars

If two cars approach the bridge at the same time one of them must stop.



One car is allowed to cross the bridge immediately, and when it is clear of the bridge the other car is allowed to cross.

If your PDF viewer will not play the animation you can see it on Youtube at this URL: https://youtu.be/nRE2B95XoHo.

3 Example 02: four-way intersection

Consider now a rural intersection of two two-lane roads.

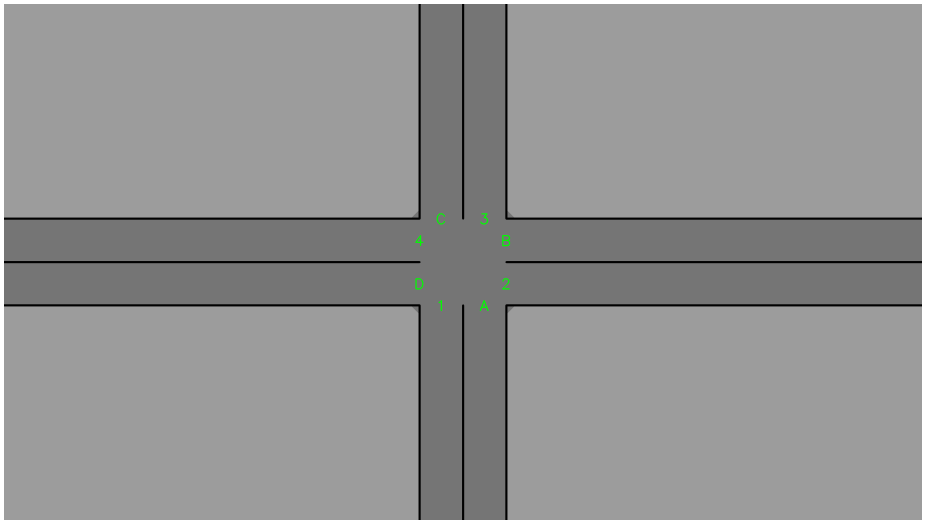


Figure 3: Example 02: four-way intersection

In figure 3 vehicles approach from the north, south, east and west. Vehicles from the south enter the intersection on lane A and can exit on lanes 1 (U-turn), 2 (right turn), 3 (atraight through) or 4 (left turn). Lanes B, C, and D likewise have four exit lanes, for a total of 16 travel paths.

3.1 Conflicts

A strict analysis of travel path conflicts shows that every entry lane has a travel path which conflicts with at least one travel path of every other entry lane. This means that only one signal face can be green at a time.

However, it is customary for a rural stoplight with little traffic to allow traffic to flow either north and south or east and west. Thus we will overlook the conflict between A4 and C2, for example, so that the signal face on lane C can be green at the same time as the signal face on lane A. We expect that, in the rare case where a southbound vehicle wants to turn left at the same time as a northbound vehicle, the vehicle operators will signal to each other so that they do not enter the intersection at the same time.

3.2 Signal Faces

We use signal faces just like the ones used for the single-lane bridge, but now we need four of them: A, B, C, and D.

3.3 Sensors

Each entry lane has two sensors: Traffic Present just before the intersection and Traffic Approaching set some distance back. In addition there is an emergency vehicle sensor which can sometimes tell which direction the emergency vehicle is coming from.

It is customary for signal faces A and C to operate together, and similarly for signal faces B and D. To accomplish this, the sensors for signal face A set both the corresponding toggles for signal face A and for signal face C, and vice-versa. The same is true for the sensors for signal faces B and D.

3.4 Timers

In addition to the timers we described for the single-lane bridge, we need the following:

3.4.1 Traffic Still Present Time

If we are trying to turn green due to a vehicle being present or approaching the intersection, but after this much time the vehicle is not present, then we stop trying to turn green. The vehicle has likely made a permissive right turn so there is no longer a need to stop the cross traffic.

3.5 Toggles

In addition to the toggles discussed in the single-lane bridge example, we need toggles to handle the emergency vehicle sensor.

3.5.1 Preempt Green

This toggle is set by the emergency vehicle detector if the emergency vehicle is coming from the direction controlled by this signal face.

3.5.2 Preempt Red

This toggle is set by the emergency vehicle detector if the emergency vehicle is coming from another direction, or if it cannot detect which direction the emergency vehicle is coming from.

3.6 Timer Durations

Here are the lengths of time that each timer runs:

Table 5: Timer Durations

Signal Face	Timer	Duration
A	Red Clearance	1.0
A	Yellow Change	5.0
A	Minimum Green	12.0
A	Maximum Green Extra	3.5
A	Traffic Gone	10.0
A	Passage	3.5
A	Maximum Green	60.0
A	Green Limit	60.0
A	Traffic Still Present	10.0
A	Red Limit	unlimited
B	Red Clearance	1.0
B	Yellow Change	5.0
B	Minimum Green	12.0
B	Maximum Green Extra	3.5
B	Traffic Gone	10.0
B	Passage	3.5
B	Maximum Green	60.0
B	Green Limit	60.0
B	Traffic Still Present	10.0
B	Red Limit	unlimited
C	Red Clearance	1.0
C	Yellow Change	5.0
C	Minimum Green	12.0
C	Maximum Green Extra	3.5
C	Traffic Gone	10.0
C	Passage	3.5
C	Maximum Green	60.0
C	Green Limit	60.0
C	Traffic Still Present	10.0

Table 5: Timer Durations continued

Signal Face	Timer	Duration
C	Red Limit	unlimited
D	Red Clearance	1.0
D	Yellow Change	5.0
D	Minimum Green	12.0
D	Maximum Green Extra	3.5
D	Traffic Gone	10.0
D	Passage	3.5
D	Maximum Green	60.0
D	Green Limit	60.0
D	Traffic Still Present	10.0
D	Red Limit	unlimited

3.7 Wiring the Finite State Machines to the Lamps

Each signal face finite state machine is wired to the lamps that it controls. Table 6 shows wiring between the signal face finite state machines and the lamps in the signal faces.

Table 6: Lamp Wiring

Signal Face	Signal Face Output Name	Actual Lamp Name
A	Steady Circular Red	Steady Circular Red
A	Steady Circular Yellow	Steady Circular Yellow
A	Steady Circular Green	Steady Circular Green
A	Flashing Circular Red	Flashing Circular Red
A	Flashing Circular Yellow	Flashing Circular Yellow
B	Steady Circular Red	Steady Circular Red
B	Steady Circular Yellow	Steady Circular Yellow
B	Steady Circular Green	Steady Circular Green
B	Flashing Circular Red	Flashing Circular Red
B	Flashing Circular Yellow	Flashing Circular Yellow
C	Steady Circular Red	Steady Circular Red
C	Steady Circular Yellow	Steady Circular Yellow

Table 6: Lamp Wiring continued

Signal Face	Signal Face Output Name	Actual Lamp Name
C	Steady Circular Green	Steady Circular Green
C	Flashing Circular Red	Flashing Circular Red
C	Flashing Circular Yellow	Flashing Circular Yellow
D	Steady Circular Red	Steady Circular Red
D	Steady Circular Yellow	Steady Circular Yellow
D	Steady Circular Green	Steady Circular Green
D	Flashing Circular Red	Flashing Circular Red
D	Flashing Circular Yellow	Flashing Circular Yellow

3.8 Wiring the Finite State Machines to the Sensors

Each signal face finite state machine is wired to the sensors for its lane. The traffic sensors for signal faces A and C are also wired to signal faces C and A, respectively, and the same for signal faces B and D.

Table 7: Sensor Wiring

Signal Face	Sensor	Toggles
A	Traffic Approaching	Traffic Approaching, C/Traffic Approaching
A	Traffic Present	Traffic Present, C/Traffic Present
A	Preempt	Preempt Red
A	Preempt from West	Preempt Red
A	Preempt from South	Preempt Green
A	Preempt from East	Preempt Red
A	Preempt from North	Preempt Red
B	Traffic Approaching	Traffic Approaching, D/Traffic Approaching
B	Traffic Present	Traffic Present, D/Traffic Present
B	Preempt	Preempt Red
B	Preempt from West	Preempt Red
B	Preempt from South	Preempt Red
B	Preempt from East	Preempt Green

Table 7: Sensor Wiring continued

Signal Face	Sensor	Toggles
B	Preempt from North	Preempt Red
C	Traffic Approaching	Traffic Approaching, A/Traffic Approaching
C	Traffic Present	Traffic Present, A/Traffic Present
C	Preempt	Preempt Red
C	Preempt from West	Preempt Red
C	Preempt from South	Preempt Red
C	Preempt from East	Preempt Red
C	Preempt from North	Preempt Green
D	Traffic Approaching	Traffic Approaching, D/Traffic Approaching
D	Traffic Present	Traffic Present, D/Traffic Present
D	Preempt	Preempt Red
D	Preempt from West	Preempt Green
D	Preempt from South	Preempt Red
D	Preempt from East	Preempt Red
D	Preempt from North	Preempt Red

3.9 Process

With four signal faces we have four finite state machines which interact with each other through system programs using their toggles.

3.9.1 States

The states are the same as for the single-lane bridge, except the Preempt Red and Preempt Green toggles will move the signal face to the correct state as quickly as possible consistent with safety, and keep it there until the sensor ceases to be triggered.

3.9.2 System Programs

Because we have decided that signal faces A and C do not conflict, we can let them both be green at the same time, and likewise for signal faces B and D.

If there were four independent signal faces the green request granted system program would have to be careful not to let two signal faces exchange green between them, freezing out a third, since an excessive wait for a green will cause

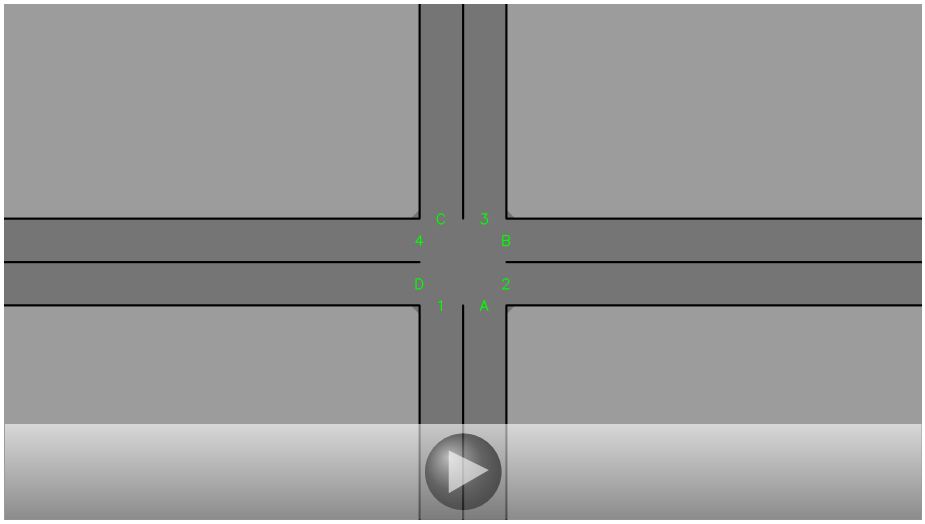
a vehicle operator to ignore the signal face and proceed into an intersection which may be occupied by another vehicle.

However, because we have tied the traffic sensors of signal faces A and C together, and the same for B and D, they will actually operate as though they were a single signal face, except in the presence of an emergency vehicle.

3.10 Illustrations

3.10.1 Traffic from All Directions

Suppose four lines of cars approach the intersection, one line from each direction.



The traffic control signal allows traffic to pass in one direction only when it is stopped in the perpendicular direction.

If your PDF viewer will not play the animation you can see it on Youtube at this URL: https://youtu.be/CDJMpd8RGm4.

4 Example 03: Complex Suburban Intersection

The final example is of a complex suburban intersection.

In figure 4 there are two lanes northorthbound, B and C, plus a dedicated left turn lane, A. For southbound traffic there are likewise two through lanes, F and G, plus a dedicated left turn lane, E. Vehicles coming from the west on lane H who wish to turn right must use the dedicated right turn lane, J. There is heavy traffic moving north and south, light traffic moving east and west.

There is a pedestrian crosswalk on the north side of the intersection and another on the south.

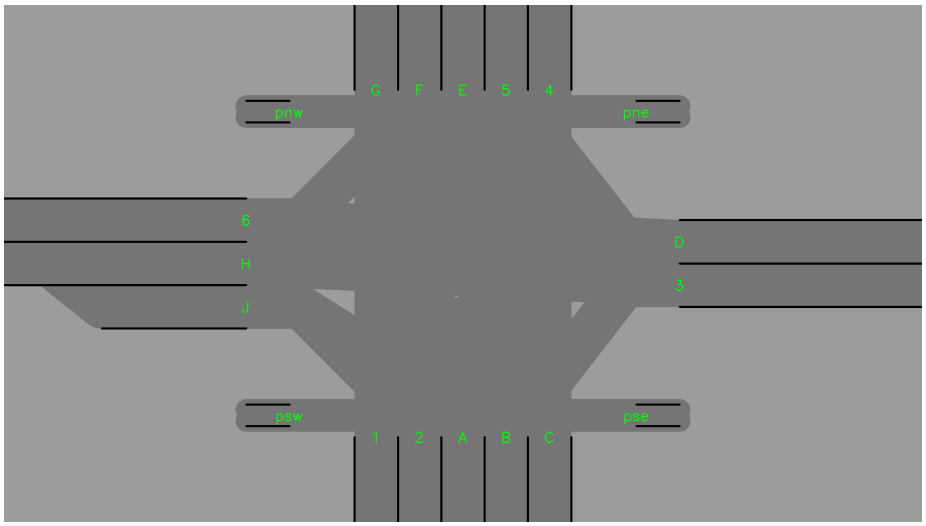


Figure 4: Example 03: Complex Suburban Intersection

4.1 Conflicts

Analysis of conflicts is more complex for this example, so we will be more formal. Each lane has a set of travel paths. For example, lane A is a dedicated left turn lane; a vehicle approaching on lane A must exit the intersection on lane 1 (wide U-turn), 2 (U-turn) or 6 (left turn). Whenever two travel paths from different entry lanes occupy the same space in the intersection they conflict, as shown in the following table.

Table 8: Travel Path Conflicts

in	out	conflicts with
A	6, 2, 1	D6, D1, D2, F2, G1, G6, H5, H4, H3, J1, pswpse, psepsw
B	5	D2, D1, D6, E5, E3, H5, H4, H3, pswpse, psepsw, pnwpne, pnepnw
C	3, 4	D1, D2, D3, D4, D6, E4, H4, H3, pswpse, psepsw, pnwpne, pnepnw
D	3, 4, 5, 6, 1, 2	A2, A1, A6, B5, C4, C3, E3, E4, E5, F2, G1, G6, H3, H4, H5, J1, J2, pnwpne, pnepnw, pswpse, psepsw
E	5, 4, 3	B5, C4, D2, D1, D6, D4, H5, H4, pnwpne, pnepnw
F	2	A2, A1, A6, D1, D2, D6, H4, H4, H3, J2, pnwpne, pnepnw, pswpse, psepsw

Table 8: Travel Path Conflicts continued

in	out	conflicts with
G	6, 1	A6, A1, A2, D2, D1, D6, H5, H4, H3, J1, pnwpne, pnepnw, pswpse, psepsw
H	5, 4	A6, B5, C4, D4, D6, D1, D2, E3, E5, E4, F2, G1, pnwpne, pnepnw
J	1, 2	A1, A2, D2, D1, F2, G1, psepsw, pswpse
psw	pse	A6, A1, A2, B5, C3, C4, D1, D2, F2, G1, J1, J2
pse	psw	A6, A1, A2, B5, C3, C4, D1, D2, F2, G1, J1, J2
pnw	pne	B5, C4, D4, D5, E3, E4, E5, F2, G6, G1, H5, H4
pne	pnw	B5, C4, D4, D5, E3, E4, E5, F2, G6, G1, H5, H4

Since the traffic control signal only controls entry to the intersection, not which travel path will be taken, we can simplify the travel path conflict table into a signal face conflict table. If any travel path from a first lane conflicts with any travel path from a second lane, we say the two lanes conflict. This means that only one of the two corresponding signal faces can be green at a time.

Table 9: Signal Face Conflict Table

signal face	conflicts with signal faces
A	pse, psw, D, F, G, H, J
pse and psw	A, B, C, D, F, G, J
B and C	pse, psw, D, E, pne, pnw, H
D	A, pse, psw, B, C, E, pne, pnw, F, G, H, J
E	B, C, D, pne, pnw, H
pne and pnw	B, C, D, E, F, G, H
F and G	A, pse, psw, D, pne, pnw, , H, J
H	A, B, C, D, E, pne, pnw, F, G
J	A, pse, psw, D, F, G

We also need a table named Partial Signal Face Conflicts. It is the same as Signal Face Conflicts except for signal face A which omits F and G, and signal face E which omits B and C. This table is used for permissive left turns.

4.2 Signal Faces

We need some additional signal faces for this intersection. In addition to the signal face used for the one-way bridge and the four-corners intersection, we have the following:

4.2.1 Right Turn Signal Face

Lane H permits only right turns, so we use a signal face in which all of the circular lamps have been replaced by right arrow lamps.

Figure 5: steady right arrow red, yellow, and green

4.2.2 Left Turn and Straight Through Signal Face

Lane G permits going straight through to lane 3 or a left turn onto lanes 4 or 5. To indicate this we use a signal face with an additionl green arrow lamp:

Figure 6: steady circular red, circular yellow, circular green, left arrow green

4.2.3 Permissive Left Turn Signal Face

Lanes A and E allow both permissive and protected left turns but not straight through. We use a signal face with all left arrows and an additional yellow lamp just above the green arrow lamp which flashes whenever it is lit. The meaning is that the left turn is permissive if the yellow arrow is flashing but it is protected (that is, oncoming traffic is stopped) if the green arrow is lit.

Figure 7: steady left arrow red, steady left arrow yellow, flashing left arrow yellow, steady left arrow green

4.2.4 Pedestrian Signal Face

For pedestrians, the signal face shows a picture which changes to indicate whether it is safe to walk, not safe to walk, or the walk time is about to end.

Figure 8: Proceed into the intersection

Figure 9: The walk condition will end in the indicated number of seconds. Do not enter the intersection unless you can cross before the walk condition ends.

Figure 10: Do not enter the intersection.

These symbols may be accompanied by audible or tactile signals for pedestrians with poor sight.

4.3 Sensors

Lanes D, G, and H do not have Traffic Approaching sensors, so their Traffic Present sensors also set their Traffic Approaching toggles.

Each pedestrian crossing is equipped with a button so the pedestrian can signal his desire to cross the street. This is equivalent to the Traffic Present sensor for vehicles.

4.4 Timers

We need additional timers to handle permissive left turns and to keep the boulevard green when there is no traffic.

4.4.1 Left Flashing Yellow Waiting Time

Lanes A and E will allow a left turn in the presence of oncoming traffic, called a permissive left turn. However, if oncoming traffic is heavy enough that a waiting vehicle cannot make its turn for Left Flashing Yellow Waiting seconds, the oncoming traffic will be stopped, thus allowing a protected left turn.

4.4.2 Minimum Left Flashing Yellow Time

Lanes A and E will allow a left turn in the presence of oncoming traffic, called a permissive left turn. Once we have turned on the left flashing yellow light, we keep it on at least Minimum Left Flashing Yellow time to make sure the left turning traffic is able to start up.

4.5 Timer Durations

Here are the lengths of times that the timers run for. Unlimited means that the timer never completes; thus there is, for example, no limit on how long signal face A can remain red.

Table 10: Timer Durations

Signal Face	Timer	Duration
A	Red Clearance	1.0
A	Yellow Change	3.5
A	Minimum Green	5.0
A	Maximum Green Extra	1.9
A	Traffic Gone	10.0
A	Passage	1.9
A	Maximum Green	20.0
A	Green Limit	60.0
A	Traffic Still Present	10.0
A	Left Flashing Yellow Waiting	15.0
A	Minimum Left Flashing Yellow	5.0
A	Red Limit	unlimited
psw	Red Clearance	3.0
psw	Yellow Change	20.0

Table 10: Timer Durations continued

Signal Face	Timer	Duration
psw	Minimum Green	6.0
psw	Maximum Green Extra	1.0
psw	Traffic Gone	10.0
psw	Passage	1.0
psw	Maximum Green	10.0
psw	Green Limit	60.0
psw	Traffic Still Present	unlimited
psw	Left Flashing Yellow Waiting	unlimited
psw	Minimum Left Flashing Yellow	unlimited
psw	Red Limit	unlimited
pse	Red Clearance	3.0
pse	Yellow Change	20.0
pse	Minimum Green	6.0
pse	Maximum Green Extra	1.0
pse	Traffic Gone	10.0
pse	Passage	1.0
pse	Maximum Green	10.0
pse	Green Limit	60.0
pse	Traffic Still Present	unlimited
pse	Left Flashing Yellow Waiting	unlimited
pse	Minimum Left Flashing Yellow	unlimited
pse	Red Limit	unlimited
B	Red Clearance	1.0
B	Yellow Change	5.0
B	Minimum Green	12.0
B	Maximum Green Extra	3.5
B	Traffic Gone	unlimited
B	Passage	3.5
B	Maximum Green	60.0
B	Green Limit	unlimited
B	Traffic Still Present	10.0

Table 10: Timer Durations continued

Signal Face	Timer	Duration
B	Left Flashing Yellow Waiting	unlimited
B	Minimum Left Flashing Yellow	unlimited
B	Red Limit	60.0
C	Red Clearance	1.0
C	Yellow Change	5.0
C	Minimum Green	12.0
C	Maximum Green Extra	3.5
C	Traffic Gone	unlimited
C	Passage	3.5
C	Maximum Green	60.0
C	Green Limit	unlimited
C	Traffic Still Present	10.0
C	Left Flashing Yellow Waiting	unlimited
C	Minimum Left Flashing Yellow	unlimited
C	Red Limit	60.0
D	Red Clearance	1.5
D	Yellow Change	3.0
D	Minimum Green	7.0
D	Maximum Green Extra	1.9
D	Traffic Gone	10.0
D	Passage	1.9
D	Maximum Green	30.0
D	Green Limit	60.0
D	Traffic Still Present	3.0
D	Left Flashing Yellow Waiting	unlimited
D	Minimum Left Flashing Yellow	unlimited
D	Red Limit	unlimited
E	Red Clearance	1.0
E	Yellow Change	3.5
E	Minimum Green	5.0
E	Maximum Green Extra	1.9

Table 10: Timer Durations continued

Signal Face	Timer	Duration
E	Traffic Gone	10.0
E	Passage	1.9
E	Maximum Green	20.0
E	Green Limit	60.0
E	Traffic Still Present	10.0
E	Left Flashing Yellow Waiting	15.0
E	Minimum Left Flashing Yellow	5.0
E	Red Limit	unlimited
pnw	Red Clearance	3.0
pnw	Yellow Change	20.0
pnw	Minimum Green	6.0
pnw	Maximum Green Extra	1.0
pnw	Traffic Gone	10.0
pnw	Passage	1.0
pnw	Maximum Green	10.0
pnw	Green Limit	60.0
pnw	Traffic Still Present	unlimited
pnw	Left Flashing Yellow Waiting	unlimited
pnw	Minimum Left Flashing Yellow	unlimited
pnw	Red Limit	unlimited
pne	Red Clearance	3.0
pne	Yellow Change	20.0
pne	Minimum Green	6.0
pne	Maximum Green Extra	1.0
pne	Traffic Gone	10.0
pne	Passage	1.0
pne	Maximum Green	10.0
pne	Green Limit	60.0
pne	Traffic Still Present	unlimited
pne	Left Flashing Yellow Waiting	unlimited
pne	Minimum Left Flashing Yellow	unlimited

Table 10: Timer Durations continued

Signal Face	Timer	Duration
pne	Red Limit	unlimited
F	Red Clearance	1.0
F	Yellow Change	5.0
F	Minimum Green	12.0
F	Maximum Green Extra	3.5
F	Traffic Gone	unlimited
F	Passage	3.5
F	Maximum Green	60.0
F	Green Limit	unlimited
F	Traffic Still Present	10.0
F	Left Flashing Yellow Waiting	unlimited
F	Minimum Left Flashing Yellow	unlimited
F	Red Limit	60.0
G	Red Clearance	1.0
G	Yellow Change	5.0
G	Minimum Green	12.0
G	Maximum Green Extra	3.5
G	Traffic Gone	unlimited
G	Passage	3.5
G	Maximum Green	60.0
G	Green Limit	unlimited
G	Traffic Still Present	10.0
G	Left Flashing Yellow Waiting	unlimited
G	Minimum Left Flashing Yellow	unlimited
G	Red Limit	60.0
H	Red Clearance	1.5
H	Yellow Change	3.0
H	Minimum Green	7.0
H	Maximum Green Extra	1.9
H	Traffic Gone	10.0
H	Passage	1.9

Table 10: Timer Durations continued

Signal Face	Timer	Duration
H	Maximum Green	30.0
H	Green Limit	60.0
H	Traffic Still Present	3.0
H	Left Flashing Yellow Waiting	unlimited
H	Minimum Left Flashing Yellow	unlimited
H	Red Limit	unlimited
J	Red Clearance	1.0
J	Yellow Change	3.0
J	Minimum Green	7.0
J	Maximum Green Extra	1.9
J	Traffic Gone	10.0
J	Passage	1.9
J	Maximum Green	30.0
J	Green Limit	60.0
J	Traffic Still Present	3.0
J	Left Flashing Yellow Waiting	unlimited
J	Minimum Left Flashing Yellow	unlimited
J	Red Limit	unlimited

4.6 Toggles

This intersection has provision for manual override by a traffic control officer. The officer has a control panel by which he can indicate which direction of traffic should be allowed. Alternatively, he can set all of the signal faces to flashing and control the traffic using hand gestures.

In addition, we need toggles to handle permissive versus protected left turns.

4.6.1 Flash Red

When a malfunction or a traffic control officer sets this toggle the signal face will set its light to flashing red.

4.6.2 Flash Yellow

When a malfunction or a traffic control officer sets this toggle the signal face will set its light to flashing yellow. Lanes A and E, which have two yellow lamps,

will flash the upper lamp, since flashing the lower lamp means that left turn is permitted.

4.6.3 Manual Red

When a traffic control operator sets this toggle the signal face will turn red as quickly as possible consistent with safety and remain red until this toggle is cleared.

4.6.4 Manual Green

when a traffic control operator sets this toggle the signal face will turn green as quickly as possible consistent with safety and remain green until this toggle is cleared.

4.6.5 Request Clearance

If a lane remains occupied after signaling that a permissive left turn is allowed, the signal face asks that oncoming traffic also be stopped by setting toggle Request Clearance.

4.6.6 Conflicting Paths are Clear

When a signal face sees that this toggle is set it can turn green. If this is a left turn signal the oncoming traffic has been stopped.

4.7 Wiring the Finite State Machines to the Lamps

Each signal face finite state machine is wired to the lamps that it controls. This lets us use arrow lamps instead of circular lamps to indicate to the motorist which travel paths are available to him. In our example, signal face A has its Steady Circular Red output connected to a lamp which shows a Steady Left Arrow Red. Table 11 shows wiring between the signal face finite state machines and the lamps in the signal faces.

Table 11: Lamp Wiring

Signal Face	Signal Face Output Name	Actual Lamp Name
A	Steady Circular Red	Steady Left Arrow Red
A	Steady Circular Yellow	Steady Left Arrow Yellow (upper)
A	Steady Circular Green	Steady Left Arrow Green
A	Flashing Circular Red	Flashing Left Arrow Red

Table 11: Lamp Wiring continued

Signal Face	Signal Face Output Name	Actual Lamp Name
A	Flashing Circular Yellow	Flashing Left Arrow Yellow (upper)
A	Flashing Left Arrow Yellow	Flashing Left Arrow Yellow (lower)
psw	Steady Circular Red	Don't Walk
psw	Steady Circular Yellow	Walk with Countdown
psw	Steady Circular Green	Walk
psw	Flashing Circular Red	Don't Walk
psw	Flashing Circular Yellow	Don't Walk
pse	Steady Circular Red	Don't Walk
pse	Steady Circular Yellow	Walk with Countdown
pse	Steady Circular Green	Walk
pse	Flashing Circular Red	Don't Walk
pse	Flashing Circular Yellow	Don't Walk
B	Steady Circular Green	Steady Circular Green
E	Steady Circular Red	Steady Left Arrow Red
E	Steady Circular Yellow	Steady Left Arrow Yellow (upper)
E	Steady Circular Green	Steady Left Arrow Green
E	Flashing Circular Red	Flashing Left Arrow Red
E	Flashing Circular Yellow	Flashing Left Arrow Yellow (upper)
E	Flashing Left Arrow Yellow	Flashing Left Arrow Yellow (lower)
pnw	Steady Circular Red	Don't Walk
pnw	Steady Circular Yellow	Walk with Countdown
pnw	Steady Circular Green	Walk
pnw	Flashing Circular Red	Don't Walk
pnw	Flashing Circular Yellow	Don't Walk
pne	Steady Circular Red	Don't Walk
pne	Steady Circular Yellow	Walk with Countdown
pne	Steady Circular Green	Walk

Table 11: Lamp Wiring continued

Signal Face	Signal Face Output Name	Actual Lamp Name
pne	Flashing Circular Red	Don't Walk
pne	Flashing Circular Yellow	Don't Walk
F	Steady Circular Green	Steady Circular Green
H	Steady Circular Green	Steady Left Arrow Green and Steady Circular Green
J	Steady Circular Red	Steady Right Arrow Red
J	Steady Circular Yellow	Steady Right Arrow Yellow
J	Steady Circular Green	Steady Right Arrow Green
J	Flashing Circular Red	Flashing Right Arrow Red
J	Flashing Circular Yellow	Flashing Right Arrow Yellow

4.8 Wiring the Finite State Machines to the Sensors

Each signal face finite state machine is wired to the sensors for its lane.

Lanes A and E have their distant sensor where the left turn lane begins; lanes B, C, E, and F have their distant sensors far enough from the intersection that a vehicle moving at the speed limit which sees the lamp turn yellow just as he trips the sensor has time to stop safely.

Lanes D, H, and J do not have distant sensors, so the output of the near sensor is used for both functions. The sensors for the pedestrian signal faces are the button that the pedestrian presses to cross.

The driving public is accustomed to signal faces which control adjacent through lanes operating together: they would think it strange if signal face B turned red while C remained green. We accomodate this by connecting the sensors for lanes B and C to both signal face B and C, and likewise for F and G.

Similarly, if pedestrians can cross the crosswalk in one direction, it is customary to also allow crossing in the opposite direction, even if the sensor has not been triggered. Thus we connect the sensors for lanes psw and pse to both signal faces psw and pse, and the sensors for lanes pnw and pne to both signal faces pnw and pne.

Table 12: Sensor Wiring

Signal Face	Sensor	Toggles
A	Traffic Approaching	Traffic Approaching
A	Traffic Present	Traffic Present

Table 12: Sensor Wiring continued

Signal Face	Sensor	Toggles
A	Flash	Flash Red
A	Preempt	Preempt Red
A	Preempt from West	Preempt Red
A	Preempt from South	Preempt Green
A	Preempt from East	Preempt Red
A	Preempt from North	Preempt Red
A	Manual Red	Manual Red
A	Manual Green	Manual Green
psw	Traffic Approaching	not connected
psw	Traffic Present	Traffic Present, pse/Traffic Present
psw	Flash	Flash Red
psw	Preempt	Preempt Red
psw	Preempt from West	Preempt Red
psw	Preempt from South	Preempt Red
psw	Preempt from East	Preempt Red
psw	Preempt from North	Preempt Red
psw	Manual Red	Manual Red
psw	Manual Green	Manual Green
pse	Traffic Approaching	not connected
pse	Traffic Present	Traffic Present, psw/Traffic Present
pse	Flash	Flash Red
pse	Preempt	Preempt Red
pse	Preempt from West	Preempt Red
pse	Preempt from South	Preempt Red
pse	Preempt from East	Preempt Red
pse	Preempt from North	Preempt Red
pse	Manual Red	Manual Red
pse	Manual Green	Manual Green
B	Traffic Approaching	Traffic Approaching, C/Traffic Approaching
B	Traffic Present	Traffic Present, C/Traffic Present

Table 12: Sensor Wiring continued

Signal Face	Sensor	Toggles
B	Flash	Flash Yellow
B	Preempt	Preempt Red
B	Preempt from West	Preempt Red
B	Preempt from South	Preempt Green
B	Preempt from East	Preempt Red
B	Preempt from North	Preempt Red
B	Manual Red	Manual Red
B	Manual Green	Manual Green
C	Traffic Approaching	Traffic Approaching, B/Traffic Approaching
C	Traffic Present	Traffic Present, B/Traffic Present
C	Flash	Flash Yellow
C	Preempt	Preempt Red
C	Preempt from West	Preempt Red
C	Preempt from South	Preempt Green
C	Preempt from East	Preempt Red
C	Preempt from North	Preempt Red
C	Manual Red	Manual Red
C	Manual Green	Manual Green
D	Traffic Approaching	not connected
D	Traffic Present	Traffic Present, Traffic Approaching
D	Flash	Flash Red
D	Preempt	Preempt Red
D	Preempt from West	Preempt Red
D	Preempt from South	Preempt Red
D	Preempt from East	Preempt Green
D	Preempt from North	Preempt Red
D	Manual Red	Manual Red
D	Manual Green	Manual Green
E	Traffic Approaching	Traffic Approaching
E	Traffic Present	Traffic Present

Table 12: Sensor Wiring continued

Signal Face	Sensor	Toggles
E	Flash	Flash Red
E	Preempt	Preempt Red
E	Preempt from West	Preempt Red
E	Preempt from South	Preempt Red
E	Preempt from East	Preempt Red
E	Preempt from North	Preempt Green
E	Manual Red	Manual Red
E	Manual Green	Manual Green
pnw	Traffic Approaching	not connected
pnw	Traffic Present	Traffic Present, pne/Traffic Present
pnw	Flash	Flash Red
pnw	Preempt	Preempt Red
pnw	Preempt from West	Preempt Red
pnw	Preempt from South	Preempt Red
pnw	Preempt from East	Preempt Red
pnw	Preempt from North	Preempt Red
pnw	Manual Red	Manual Red
pnw	Manual Green	Manual Green
pne	Traffic Approaching	not connected
pne	Traffic Present	Traffic Present, pnw/Traffic Present
pne	Flash	Flash Red
pne	Preempt	Preempt Red
pne	Preempt from West	Preempt Red
pne	Preempt from South	Preempt Red
pne	Preempt from East	Preempt Red
pne	Preempt from North	Preempt Red
pne	Manual Red	Manual Red
pne	Manual Green	Manual Green
F	Traffic Approaching	Traffic Approaching, G/Traffic Approaching
F	Traffic Present	Traffic Present, G/Traffic Present

Table 12: Sensor Wiring continued

Signal Face	Sensor	Toggles
F	Flash	Flash Yellow
F	Preempt	Preempt Red
F	Preempt from West	Preempt Red
F	Preempt from South	Preempt Red
F	Preempt from East	Preempt Red
F	Preempt from North	Preempt Green
F	Manual Red	Manual Red
F	Manual Green	Manual Green
G	Traffic Approaching	Traffic Approaching, F/Traffic Approaching
G	Traffic Present	Traffic Present, F/Traffic Present
G	Flash	Flash Yellow
G	Preempt	Preempt Red
G	Preempt from West	Preempt Red
G	Preempt from South	Preempt Red
G	Preempt from East	Preempt Red
G	Preempt from North	Preempt Green
G	Manual Red	Manual Red
G	Manual Green	Manual Green
H	Traffic Approaching	not connected
H	Traffic Present	Traffic Present, Traffic Approaching
H	Flash	Flash Red
H	Preempt	Preempt Red
H	Preempt from West	Preempt Green
H	Preempt from South	Preempt Red
H	Preempt from East	Preempt Red
H	Preempt from North	Preempt Red
H	Manual Red	Manual Red
H	Manual Green	Manual Green
J	Traffic Approaching	not connected
J	Traffic Present	Traffic Present, Traffic Approaching

Table 12: Sensor Wiring continued

Signal Face	Sensor	Toggles
J	Flash	Flash Red
J	Preempt	Preempt Red
J	Preempt from West	Preempt Green
J	Preempt from South	Preempt Red
J	Preempt from East	Preempt Red
J	Preempt from North	Preempt Red
J	Manual Red	Manual Red
J	Manual Green	Manual Green

4.9 Process

We have nine signal faces, each with one or two sensors, plus an emergency vehicle sensor and manual override controls.

4.9.1 States

Here are the full details about each state, and each substate within them.

When a signal face's finite state machine enters a particular substate there are actions which are executed. While it is in that substate there are conditions that will cause it to exit the substate and enter another.

Red The Red major state shows a red light, which means traffic in this lane must stop. When the traffic light has been red for Red Clearance Time, the finite state machine sets its Cleared toggle, which is tested by other signal faces to see if they can turn green. If a vehicle or pedestrian arrives at this signal face it starts the process of itself tturning green.

Here are the details of the Red state:

Substate Waiting for Clearance

Entry Actions

- Set lamp Steady Circular Red.
- Clear toggle Cleared.
- Start timer Red Clearance.
- Start timer Red Limit.

Exits

- **condition:** timer is completed Red Clearance
  destination: State Red Substate Travel Path is Clear

Substate Travel Path is Clear

Entry Actions

- Set toggle Cleared.
- Clear toggle Clearance Requested.
- Clear toggle Traffic Present.
- Clear toggle Traffic Flowing.
- Clear toggle Traffic Approaching.
- Clear toggle Preempt Red.
- Clear toggle Manual Red.
- Clear toggle Flash Red.
- Clear toggle Flash Yellow.
- Clear toggle Request Green.
- Clear toggle Request Partial Clearance.
- Clear toggle Request Clearance.
- Clear toggle Green Request Granted.

Exits

- **condition:** toggle is true Preempt Red
  destination: State Red Substate Travel Path is Clear
- **condition:** toggle is true Manual Red
  destination: State Red Substate Travel Path is Clear
- **condition:** toggle is true Flash Red
  destination: State Red Substate Flashing
- **condition:** toggle is true Flash Yellow
  destination: State Yellow Substate Flashing
- **condition:** toggle is true Traffic Approaching
  destination: State Red Substate Going Green 1
- **condition:** toggle is true Traffic Present
  destination: State Red Substate Going Green 1
- **condition:** toggle is true Preempt Green
  destination: State Red Substate Going Green 4
- **condition:** toggle is true Manual Green
  destination: State Red Substate Going Green 4
- **condition:** timer is completed Red Limit
  destination: State Red Substate Going Green 4

Substate Going Green 1

Entry Actions

- Set toggle Request Green.
- Clear toggle Traffic Present.
- Clear toggle Traffic Approaching.
- Start timer Traffic Still Present.

Exits

- **condition:** timer not complete Traffic Still Present
  destination: State Red Substate Going Green 2

Substate Going Green 2

Entry Actions

- Clear toggle Traffic Present.
- Clear toggle Traffic Approaching.

Exits

- **condition:** toggle is true Preempt Red
  destination: State Red Substate Travel Path is Clear
- **condition:** toggle is true Manual Red
  destination: State Red Substate Travel Path is Clear
- **condition:** toggle is true Flash Red
  destination: State Red Substate Travel Path is Clear
- **condition:** toggle is true Flash Yellow
  destination: State Red Substate Travel Path is Clear
- **condition:** toggle is true Green Request Granted
  destination: State Red Substate Going Green 3
- **condition:** timer is completed Traffic Still Present
  and: toggle is false Traffic Present
  destination: State Red Substate Travel Path is Clear
- **condition:** timer not complete Traffic Still Present
  destination: State Red Substate Going Green 2

Substate Going Green 3

Entry Actions

- Clear toggle Request Green.
- Set toggle Request Partial Clearance.
- Clear toggle Traffic Present.
- Clear toggle Traffic Approaching.

Exits

- **condition:** toggle is true Preempt Red
  destination: State Red Substate Travel Path is Clear
- **condition:** toggle is true Manual Red
  destination: State Red Substate Travel Path is Clear
- **condition:** toggle is true Flash Red
  destination: State Red Substate Travel Path is Clear
- **condition:** toggle is true Flash Yellow
  destination: State Red Substate Travel Path is Clear
- **condition:** toggle is true Partial Conflicting Paths are Clear

and: toggle is false Conflicting Paths are Clear
destination: State Yellow Substate Left Flashing 1
- **condition:** toggle is true Conflicting Paths are Clear
destination: State Green Substate Minimum Green
- **condition:** timer is completed Traffic Still Present
and: toggle is false Traffic Present
destination: State Red Substate Travel Path is Clear
- **condition:** timer not complete Traffic Still Present
destination: State Red Substate Going Green 3

Substate Going Green 4

Entry Actions
- Set toggle Request Green.

Exits
- **condition:** toggle is true Preempt Red
destination: State Red Substate Travel Path is Clear
- **condition:** toggle is true Manual Red
destination: State Red Substate Travel Path is Clear
- **condition:** toggle is true Flash Red
destination: State Red Substate Travel Path is Clear
- **condition:** toggle is true Flash Yellow
destination: State Red Substate Travel Path is Clear
- **condition:** toggle is true Green Request Granted
destination: State Red Substate Going Green 5

Substate Going Green 5

Entry Actions
- Clear toggle Request Green.
- Set toggle Request Partial Clearance.

Exits
- **condition:** toggle is true Preempt Red
destination: State Red Substate Travel Path is Clear
- **condition:** toggle is true Manual Red
destination: State Red Substate Travel Path is Clear
- **condition:** toggle is true Flash Red
destination: State Red Substate Travel Path is Clear
- **condition:** toggle is true Flash Yellow
destination: State Red Substate Travel Path is Clear
- **condition:** toggle is true Partial Conflicting Paths are Clear
and: toggle is false Conflicting Paths are Clear
destination: State Yellow Substate Left Flashing 1

- **condition:** toggle is true Conflicting Paths are Clear
  destination: State Green Substate Minimum Green

Substate Flashing

Entry Actions

- Set lamp Flashing Circular Red.
- Clear toggle Flash Red.

Exits

- **condition:** toggle is false Flash Red
  and: toggle is false Flash Yellow
  destination: State Red Substate Waiting for Clearance
- **condition:** toggle is false Flash Red
  and: toggle is true Flash Yellow
  destination: State Yellow Substate Flashing
- **condition:** toggle is true Flash Red
  destination: State Red Substate Flashing

Green The Green major state shows a green light, which means traffic in this lane may proceed through the intersection. When the light turns green we keep the light green long enough for the traffic to get moving. Afterwards if another signal face wants us to turn red we wait for a break in the traffic. If there is no break in the traffic for a while we turn red anyway. If an emergency vehicle is present we turn red as quickly as we safely can.

Substate Minimum Green

Entry Actions

- Set lamp Steady Circular Green.
- Clear toggle Green Request Granted.
- Clear toggle Cleared.
- Clear toggle Request Partial Clearance.
- Clear toggle Request Clearance.
- Start timer Minimum Green.
- Start timer Maximum Green.
- Start timer Green Limit.
- Set toggle Traffic Flowing.

Exits

- **condition:** timer is completed Minimum Green
  destination: State Green Substate Looking for Gap 1

Substate Looking for Gap 1

Entry Actions

- Start timer Passage.

- Start timer Traffic Gone.
- Clear toggle Traffic Present.
- Clear toggle Traffic Approaching.
- Clear toggle Preempt Green.
- Clear toggle Manual Green.

Exits

- **condition:** toggle is true Preempt Red
  destination: State Yellow Substate Going Red
- **condition:** toggle is true Flash Red
  destination: State Yellow Substate Going Red
- **condition:** toggle is true Flash Yellow
  destination: State Yellow Substate Flashing
- **condition:** toggle is true Preempt Green
  destination: State Green Substate Looking for Gap 2
- **condition:** toggle is true Manual Green
  destination: State Green Substate Looking for Gap 2
- **condition:** timer is completed Passage
  and: toggle is true Clearance Requested
  destination: State Yellow Substate Going Red
- **condition:** timer is completed Green Limit
  destination: State Yellow Substate Going Red
- **condition:** timer is completed Traffic Gone
  destination: State Yellow Substate Going Red
- **condition:** timer is completed Maximum Green
  destination: State Green Substate Looking for Gap 2
- **condition:** toggle is true Traffic Approaching
  destination: State Green Substate Looking for Gap 1

Substate Looking for Gap 2

Entry Actions

- Clear toggle Preempt Green.
- Clear toggle Manual Green.

Exits

- **condition:** toggle is true Preempt Red
  destination: State Yellow Substate Going Red
- **condition:** toggle is true Manual Red
  destination: State Yellow Substate Going Red
- **condition:** toggle is true Flash Red
  destination: State Yellow Substate Going Red
- **condition:** toggle is true Flash Yellow

destination: State Yellow Substate Flashing
- **condition:** toggle is true Clearance Requested
  destination: State Green Substate Looking for Gap 3
- **condition:** toggle is true Traffic Approaching
  destination: State Green Substate Looking for Gap 4
- **condition:** timer is completed Green Limit
  and: toggle is false Preempt Green
  and: toggle is false Manual Green
  destination: State Yellow Substate Going Red

Substate Looking for Gap 3

Entry Actions
- Clear toggle Preempt Green.
- Clear toggle Manual Green.
- Start timer Maximum Green Extra.

Exits
- **condition:** toggle is true Preempt Red
  destination: State Yellow Substate Going Red
- **condition:** toggle is true Manual Red
  destination: State Yellow Substate Going Red
- **condition:** toggle is true Flash Red
  destination: State Yellow Substate Going Red
- **condition:** toggle is true Flash Yellow
  destination: State Yellow Substate Flashing
- **condition:** toggle is true Clearance Requested
  and: timer is completed Passage
  destination: State Yellow Substate Going Red
- **condition:** toggle is true Clearance Requested
  and: timer is completed Maximum Green Extra
  destination: State Yellow Substate Going Red
- **condition:** timer is completed Green Limit
  and: toggle is false Preempt Green
  and: toggle is false Manual Green
  destination: State Yellow Substate Going Red
- **condition:** toggle is true Traffic Approaching
  destination: State Green Substate Looking for Gap 5
- **condition:** toggle is false Clearance Requested
  destination: State Green Substate Looking for Gap 2

Substate Looking for Gap 4

Entry Actions

- Clear toggle Preempt Green.
- Clear toggle Manual Green.
- Clear toggle Traffic Approaching.
- Start timer Passage.
- Start timer Traffic Gone.

Exits

- **condition:** toggle is true Preempt Red
  destination: State Yellow Substate Going Red
- **condition:** toggle is true Manual Red
  destination: State Yellow Substate Going Red
- **condition:** toggle is true Flash Red
  destination: State Yellow Substate Going Red
- **condition:** toggle is true Flash Yellow
  destination: State Yellow Substate Flashing
- **condition:** toggle is true Clearance Requested
  and: timer is completed Passage
  destination: State Yellow Substate Going Red
- **condition:** timer is completed Green Limit
  and: toggle is false Preempt Green
  and: toggle is false Manual Green
  destination: State Yellow Substate Going Red
- **condition:** timer is completed Traffic Gone
  and: toggle is false Preempt Green
  and: toggle is false Manual Green
  destination: State Yellow Substate Going Red
- **condition:** toggle is true Traffic Approaching
  destination: State Green Substate Looking for Gap 4

Substate Looking for Gap 5

Entry Actions

- Clear toggle Preempt Green.
- Clear toggle Manual Green.
- Clear toggle Traffic Approaching.
- Start timer Passage.
- Start timer Traffic Gone.

Exits

- **condition:** toggle is true Preempt Red
  destination: State Yellow Substate Going Red
- **condition:** toggle is true Manual Red
  destination: State Yellow Substate Going Red

- **condition:** toggle is true Flash Red
  destination: State Yellow Substate Going Red
- **condition:** toggle is true Flash Yellow
  destination: State Yellow Substate Flashing
- **condition:** toggle is true Clearance Requested
  and: timer is completed Passage
  destination: State Yellow Substate Going Red
- **condition:** toggle is true Clearance Requested
  and: timer is completed Maximum Green Extra
  destination: State Yellow Substate Going Red
- **condition:** timer is completed Green Limit
  and: toggle is false Preempt Green
  and: toggle is false Manual Green
  destination: State Yellow Substate Going Red
- **condition:** timer is completed Traffic Gone
  and: toggle is false Preempt Green
  and: toggle is false Manual Green
  destination: State Yellow Substate Going Red
- **condition:** toggle is true Traffic Approaching
  destination: State Green Substate Looking for Gap 5
- **condition:** toggle is false Clearance Requested
  destination: State Green Substate Looking for Gap 2

Yellow The Yellow state is an intermediate state between green and red, and when flashing means that there may be conflicting traffic. On left turn signal faces with a fourth light that shows a flashing yellow left arrow, that light is included in the Yellow state.

Substate Going Red

Entry Actions

- Set lamp Steady Circular Yellow.
- Clear toggle Cleared.
- Start timer Yellow Change.

Exits

- **condition:** timer is completed Yellow Change
  destination: State Red Substate Waiting for Clearance

Substate Left Flashing 1

Entry Actions

- Set lamp Flashing Left Arrow Yellow.
- Clear toggle Green Request Granted.

- Clear toggle Cleared.
- Set toggle Traffic Flowing.
- Start timer Minimum Left Flashing Yellow.
- Start timer Left Flashing Yellow Waiting.
- Start timer Green Limit.

Exits

- **condition:** toggle is true Preempt Red
  destination: State Yellow Substate Going Red
- **condition:** toggle is true Manual Red
  destination: State Yellow Substate Going Red
- **condition:** toggle is true Flash Red
  destination: State Yellow Substate Going Red
- **condition:** toggle is true Flash Yellow
  destination: State Yellow Substate Flashing
- **condition:** timer is completed Minimum Left Flashing Yellow
  destination: State Yellow Substate Left Flashing 2

Substate Left Flashing 2

Entry Actions

- Clear toggle Traffic Present.
- Clear toggle Traffic Approaching.

Exits

- **condition:** toggle is true Preempt Red
  destination: State Yellow Substate Going Red
- **condition:** toggle is true Flash Red
  destination: State Yellow Substate Going Red
- **condition:** toggle is true Flash Yellow
  destination: State Yellow Substate Flashing
- **condition:** toggle is true Conflicting Paths are Clear
  destination: State Green Substate Minimum Green
- **condition:** timer is completed Green Limit
  and: toggle is false Preempt Green
  and: toggle is false Manual Green
  destination: State Yellow Substate Going Red
- **condition:** timer not complete Left Flashing Yellow Waiting
  and: toggle is true Traffic Approaching
  destination: State Yellow Substate Left Flashing 2
- **condition:** timer not complete Left Flashing Yellow Waiting
  and: toggle is true Traffic Present

destination: State Yellow Substate Left Flashing 2

- **condition:** timer is completed Left Flashing Yellow Waiting
  and: toggle is false Traffic Present
  destination: State Yellow Substate Going Red
- **condition:** timer is completed Left Flashing Yellow Waiting
  and: toggle is true Traffic Present
  destination: State Yellow Substate Going Green

Substate Flashing

Entry Actions

- Set lamp Flashing Circular Yellow.
- Clear toggle Flash Yellow.

Exits

- **condition:** toggle is false Flash Yellow
  and: toggle is false Flash Red
  destination: State Red Substate Waiting for Clearance
- **condition:** toggle is false Flash Yellow
  and: toggle is true Flash Red
  destination: State Red Substate Flashing
- **condition:** toggle is true Flash Yellow
  and: toggle is false Flash Red
  destination: State Yellow Substate Flashing
- **condition:** toggle is true Flash Yellow
  and: toggle is true Flash Red
  destination: State Red Substate Flashing

Substate Going Green

Entry Actions

- Set toggle Request Clearance.

Exits

- **condition:** toggle is true Preempt Red
  destination: State Yellow Substate Going Red
- **condition:** toggle is true Manual Red
  destination: State Yellow Substate Going Red
- **condition:** toggle is true Preempt Green
  destination: State Green Substate Minimum Green
- **condition:** toggle is true Manual Green
  destination: State Green Substate Minimum Green
- **condition:** toggle is true Flash Red
  destination: State Yellow Substate Going Red
- **condition:** toggle is true Flash Yellow

destination: State Yellow Substate Flashing

- **condition:** toggle is true Conflicting Paths are Clear
  destination: State Green Substate Minimum Green

The State Diagram Summary in figure 11 summarizes the most significant states, substates and transitions of the finite state machines:

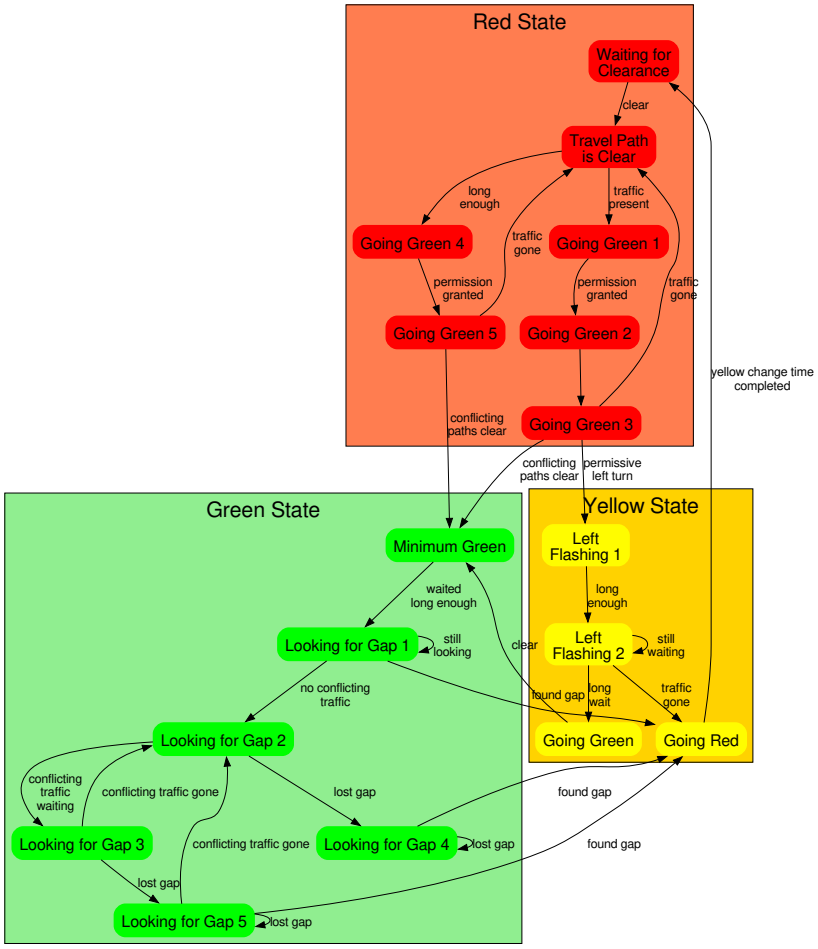


Figure 11: State Diagram Summary

4.9.2 System Programs

Communication between traffic signal face finite state machiness is handled by system programs. These system programs run constantly, reacting to toggles in the signal faces by setting toggles in other signal faces.

Green Request Granted To prevent two signal faces from bouncing green time between each other, locking out a third signal face, this system program makes sure that traffic never has to wait too long for a green light.

The Green Request Granted system program maintains a persistent list of signal faces that are requesting green, a list of signal faces that are allowed to turn green and a list of signal faces that have turned green since the currently waiting signal face has had its chance. All of these lists start empty.

Go through all of the signal faces looking for those with toggle Request Green true. Add each such signal face to the list of signal faces that are requesting green, unless the signal face is already on the list or is in the list of signal faces allowed to turn green.

If the list of signal faces allowed to turn green is empty, move the oldest signal face on the list of signal faces that are requesting green to the list of signal faces allowed to turn green and empty the list of signal faces that have turned green since the currently waiting signal face has had its chance.

Although we wish to allow the signal face that has been on the signal faces requesting to turn green list the longest to turn green as soon as possible, we can let other signal faces turn green at the same time or sooner if they will not delay this signal face from turning green.

If the oldest signal face on the list of signal faces that are requesting to turn green does not conflict with any of the signal faces that are already allowed to turn green, move it from the list of signal faces that are requesting to turn green to the list of signal faces that are allowed to turn green and empty the list of signal faces that have turned green since the currently waiting signal face has had its chance.

Keep doing the above until the list is empty or the oldest signal face on the list cannot move because of a conflict.

Now we try to let some signal faces turn green out of order, being careful not to allow any other signal face to be starved out of any opportunity to turn green.

Provided the oldest signal face on the list of signal faces requesting to turn green has not been waiting too long, go through the list of signal faces that are requesting to turn green starting with the oldest. For each such signal face that does not conflict with any of the signal faces already in the set of signal faces allowed to turn green, and is not in the list of signal faces that have turned green since the currently waiting signal face has had its chance, move that signal face to the list of signal faces allowed to turn green and add it to the list of signal faces that have turned green since the currently waiting signal face has had its chance.

Go through the list of signal faces allowed to turn green. For any for which toggle Traffic Flowing is true, remove them from the set since they have

now turned green.

Go through the list of signal faces allowed to turn green. For each such signal face, set its Green Request Granted toggle, telling it that it can now turn green.

Clearance Requested When a signal face wants to turn green, it must wait for all conflicting signal faces to become clear. This system program conveys the request for clearance to the necessary signal faces.

Go through all of the signal faces looking for those with toggle Request Clearance true. For each such signal face, consult the traffic signal conflict table to see which signal faces conflict with this one. For each such signal face, set its Clearance Requested toggle.

Partial Clearance Requested Go through all of the signal faces looking for those with toggle Request Partial Clearance true. For each such signal face, consult the partial signal face conflict table to see which signal faces conflict with this one. For each such signal face, set its Clearance Requested toggle.

This is the same as Clearance Requested, but we use the partial signal face conflict table, which matches the signal face conflict table except for the left turn lanes, where their conflict with oncoming traffic is omitted. This lets left turners try to make a permissive left turn, but if they cannot the oncoming traffic will also be stopped.

Conflicting Paths are Clear Go through the signal faces looking for those with toggle Request Clearance or toggle Request Partial Clearance true. For each such signal face, consult the signal face conflict table to determine which signal faces conflict with this one. If all of those signal faces have their Cleared toggles true, set the Conflicting Paths are Clear toggle in this signal face.

Partial Conflicting Paths are Clear Go through the signal faces looking for those with toggle Request Partial Clearance true. For each such signal face, consult the partial signal face conflict table to determine which signal faces conflict with this one. If all of those signal faces have their Clear toggles true, set the Partial Conflicting Paths are Clear toggle in this signal face.

Safety Check Safety Check is a different kind of system program. It does not monitor toggles from the various signal faces but instead checks for unsafe conditions.

An error in the description of the finite state machine, or an error in the implementation of the finite state machine driver or the system programs may cause the signal faces to get into unintended states, such that intersecting traffic flows are permitted in the intersection. Sucn a condition is unsafe. Check for incompatible states and, if such a state is found, set the intersection to flashing.

4.10 Illustrations

4.10.1 Idle

If there is no traffic, signals faces A, D, E, H, J, and the pedestrian signal faces will remain red since their Red Limit timers have an infinite duration; however, signal faces B, C, F, and G will proceed to substate Going Green 1 when their Red Limit timers complete after 60 seconds.

In substate Going Green 1, system program Green Request Granted will notice that signal faces B, C, F, and G have their Request Green toggles true. The system program will place all four signal faces on its list of traffic signals requesting to turn green. It will move one of them to the list of signal faces allowed to turn green. Assume it is signal face B. It will then go through the three remaining signal faces and discover that signal face C does not have a conflict with B and so move it to the set of signal faces allowed to turn green. Similarly, signal face F has no conflict with B or C, and G has no conflict with B, C, or F, so we end up with B, C, F and G on the list of signal faces allowed to turn green.

Signal faces B, C, F, and G will proceed to state Red substate Going Green 2 where they will set toggle Request Partial Clearance.

System Program Partial Clearance Requested will notice that signal faces B, C, F, and G have Request Partial Clearance true, and will consider setting toggle Clearance Requested in signal faces D, E, H, J, and the pedestrian signal faces. However, those signal faces are in state Red substate Travel Path is Clear so they all have their Cleared toggles set.

The Partial Conflicting Paths are Clear system program will notice that the signal faces that partially conflict with B, C, F, and G are clear, so will set the Partial Conflicting Paths are Clear toggle in signal faces B, F, F, and G. Similarly, the Conflicting Paths are Clear system program will set the Conflicting Paths are Clear toggle in those same signal faces.

Signal faces B, C, F, and G will proceed from state Red substate Going Green 2 to state Green substate Minimum Green. This will cause those signal faces to turn green and set toggle Traffic Flowing.

System program Green Request Granted will notice that signal faces B, C, F, and G have their Traffic Flowing toggle true, and so will remove them from the list of signal faces allowed to turn green. This will cause the list to be empty.

The net effect is that after 60 seconds signal faces B, C, F, and G turn green. Because the Green Limit timer duration for signal faces B, C, F, and G is unlimited they will remain green unless a conflicting signal face needs to turn green. Because the Red Limit timer duration for the other signal faces is unlimited they will stay red unless some traffic appears on their lanes.

We will call this situation, with signal faces B, C, F, and G green and the others red and clear the idle condition for example 03, since it will persist in the absence of traffic.

This table of events details the progression from power on to the idle condition.

Table 13: Power On to Idle State, example 03

Time	Lane	Event
000.000	A	Enter state Red substate Waiting for Clearance.
	A	Set lamp to Steady Left Arrow Red.
	psw	Enter state Red substate Waiting for Clearance.
	psw	Set lamp to Don't Walk.
	pse	Enter state Red substate Waiting for Clearance.
	pse	Set lamp to Don't Walk.
	B	Enter state Red substate Waiting for Clearance.
	B	Set lamp to Steady Circular Red.
	C	Enter state Red substate Waiting for Clearance.
	C	Set lamp to Steady Circular Red.
	D	Enter state Red substate Waiting for Clearance.
	D	Set lamp to Steady Circular Red.
	E	Enter state Red substate Waiting for Clearance.
	E	Set lamp to Steady Left Arrow Red.
	pnw	Enter state Red substate Waiting for Clearance.
	pnw	Set lamp to Don't Walk.
	pne	Enter state Red substate Waiting for Clearance.
	pne	Set lamp to Don't Walk.
	F	Enter state Red substate Waiting for Clearance.
	F	Set lamp to Steady Circular Red.
	G	Enter state Red substate Waiting for Clearance.
	G	Set lamp to Steady Circular Red.
	H	Enter state Red substate Waiting for Clearance.
	H	Set lamp to Steady Circular Red.
	J	Enter state Red substate Waiting for Clearance.
	J	Set lamp to Steady Right Arrow Red.
001.000	A	Enter state Red substate Travel Path is Clear.
	A	Set toggle Cleared.
	B	Enter state Red substate Travel Path is Clear.
	B	Set toggle Cleared.
	C	Enter state Red substate Travel Path is Clear.

Table 13: Power On to Idle State, example 03 continued

Time	Lane	Events
	C	Set toggle Cleared.
	E	Enter state Red substate Travel Path is Clear.
	E	Set toggle Cleared.
	F	Enter state Red substate Travel Path is Clear.
	F	Set toggle Cleared.
	G	Enter state Red substate Travel Path is Clear.
	G	Set toggle Cleared.
	J	Enter state Red substate Travel Path is Clear.
	J	Set toggle Cleared.
001.500	D	Enter state Red substate Travel Path is Clear.
	D	Set toggle Cleared.
	H	Enter state Red substate Travel Path is Clear.
	H	Set toggle Cleared.
003.000	psw	Enter state Red substate Travel Path is Clear.
	psw	Set toggle Cleared.
	pse	Enter state Red substate Travel Path is Clear.
	pse	Set toggle Cleared.
	pnw	Enter state Red substate Travel Path is Clear.
	pnw	Set toggle Cleared.
	pne	Enter state Red substate Travel Path is Clear.
	pne	Set toggle Cleared.
060.000	B	Enter state Red substate Going Green 4.
	B	Set toggle Request Green.
	C	Enter state Red substate Going Green 4.
	C	Set toggle Request Green.
	F	Enter state Red substate Going Green 4.
	F	Set toggle Request Green.
	G	Enter state Red substate Going Green 4.
	G	Set toggle Request Green.
	B	Set toggle Green Request Granted by system program Green Request Granted.

Table 13: Power On to Idle State, example 03 continued

Time	Lane	Events
	C	Set toggle Green Request Granted by system program Green Request Granted.
	F	Set toggle Green Request Granted by system program Green Request Granted.
	G	Set toggle Green Request Granted by system program Green Request Granted.
	B	Enter state Red substate Going Green 5.
	B	Clear toggle Request Green.
	B	Set toggle Request Partial Clearance.
	C	Enter state Red substate Going Green 5.
	C	Clear toggle Request Green.
	C	Set toggle Request Partial Clearance.
	F	Enter state Red substate Going Green 5.
	F	Clear toggle Request Green.
	F	Set toggle Request Partial Clearance.
	G	Enter state Red substate Going Green 5.
	G	Clear toggle Request Green.
	G	Set toggle Request Partial Clearance.
	B	Set toggle Conflicting Paths are Clear by system program Conflicting Paths are Clear.
	C	Set toggle Conflicting Paths are Clear by system program Conflicting Paths are Clear.
	F	Set toggle Conflicting Paths are Clear by system program Conflicting Paths are Clear.
	G	Set toggle Conflicting Paths are Clear by system program Conflicting Paths are Clear.
	B	Set toggle Partial Conflicting Paths are Clear by system program Partial Conflicting Paths are Clear.
	C	Set toggle Partial Conflicting Paths are Clear by system program Partial Conflicting Paths are Clear.
	F	Set toggle Partial Conflicting Paths are Clear by system program Partial Conflicting Paths are Clear.
	G	Set toggle Partial Conflicting Paths are Clear by system program Partial Conflicting Paths are Clear.

Table 13: Power On to Idle State, example 03 continued

Time	Lane	Events
	B	Enter state Green substate Minimum Green.
	B	Set lamp to Steady Circular Green.
	B	Clear toggle Green Request Granted.
	B	Clear toggle Cleared.
	B	Clear toggle Request Partial Clearance.
	B	Set toggle Traffic Flowing.
	C	Enter state Green substate Minimum Green.
	C	Set lamp to Steady Circular Green.
	C	Clear toggle Green Request Granted.
	C	Clear toggle Cleared.
	C	Clear toggle Request Partial Clearance.
	C	Set toggle Traffic Flowing.
	F	Enter state Green substate Minimum Green.
	F	Set lamp to Steady Circular Green.
	F	Clear toggle Green Request Granted.
	F	Clear toggle Cleared.
	F	Clear toggle Request Partial Clearance.
	F	Set toggle Traffic Flowing.
	G	Enter state Green substate Minimum Green.
	G	Set lamp to Steady Circular Green.
	G	Clear toggle Green Request Granted.
	G	Clear toggle Cleared.
	G	Clear toggle Request Partial Clearance.
	G	Set toggle Traffic Flowing.
	B	Clear toggle Conflicting Paths are Clear by system program Conflicting Paths are Clear.
	C	Clear toggle Conflicting Paths are Clear by system program Conflicting Paths are Clear.
	F	Clear toggle Conflicting Paths are Clear by system program Conflicting Paths are Clear.
	G	Clear toggle Conflicting Paths are Clear by system program Conflicting Paths are Clear.

Table 13: Power On to Idle State, example 03 continued

Time	Lane	Events
	B	Clear toggle Partial Conflicting Paths are Clear by system program Partial Conflicting Paths are Clear.
	C	Clear toggle Partial Conflicting Paths are Clear by system program Partial Conflicting Paths are Clear.
	F	Clear toggle Partial Conflicting Paths are Clear by system program Partial Conflicting Paths are Clear.
	G	Clear toggle Partial Conflicting Paths are Clear by system program Partial Conflicting Paths are Clear.
072.000	B	Enter state Green substate Looking for Gap 1.
	C	Enter state Green substate Looking for Gap 1.
	F	Enter state Green substate Looking for Gap 1.
	G	Enter state Green substate Looking for Gap 1.
120.000	B	Enter state Green substate Looking for Gap 2.
	C	Enter state Green substate Looking for Gap 2.
	F	Enter state Green substate Looking for Gap 2.
	G	Enter state Green substate Looking for Gap 2.

4.10.2 Pedestrian Crossing on South Side of Intersection

A pedestrian who wishes to cross the boulevard on the south side presses his button. Assuming we are in the idle condition with signal faces B, C, F, and G green and with A, D, E, H, J, and the pedestrian signal faces red and clear.

Signal faces psw and pse will proceed to substate Going Green 1 where they will set toggle Request Green. The Green Request Granted system program will act as described above to set the Green Request Granted toggle since no other signal faces are waiting to turn green. Signal faces psw and pse will then proceed to substate Going Green 2 where they will set toggle Request Partial Clearance. System program Partial Conflicting Paths are Clear will set the Clearance Requested toggles in signal faces B, C, F, and G, but not in signal faces A, D and J because they are aleady clear. Signal faces B, C, F, and G are in state Green substate Waiting for Clearance Request because their Green Limit timer has a duration of infinity and they have seen no recent traffic.

Signal faces B, C, F and G will enter state Yellow substate Going Red. When their Yellow Change timers complete they will proceed to state Red substate Waiting for Clearance. When their Red Clearance timers complete they will go to substate Travel Path is Clear and set toggle Cleared.

The Conflicting Paths are Clear system program will notice that signal faces A, B, C, D, F, G, and J are all clear and set the Conflicting Paths are Clear toggle in signal faces psw amd pse. Similarly, the Partial Conflicting Paths are

Clear system program will set the Partial Conflicting Paths are Clear toggle.

Signal faces psw and pse will transition to state Green substate Minimum Green. This will cause the pedestrian signs to display a walking man, the equivalent of green. Assuming there is no other traffic, signal faces pse and psw will remain green until the Red Limit timers complete on signal faces B, C, F, and G. This will cause signal faces pse and psw to follow the progression described above for signal paths B, C, F, and G. Signal faces pse and psw will transition to state Yellow substate Going Red, where they will display the hand with a countdown timer showing how many seconds are left in the Yellow Change timer. When the Yellow Change timer is complete signal faces psw and pse will transition to the Red state, substate Waiting for Clearance. When their Red Clearance timers completes they will transition to substate Travel Path is Clear and set the Cleared toggle.

Signal faces B, C, F, and G will then proceed as described above in the Idle illustration to turn green.

The following describes the events in detail.

Table 14: Pedestrian Crosses

Time	Lane	Event
200.000	psw	Pedestrian 0000 starts on travel path pswpse speed 03.5 fps.
202.858	psw	Sensor Traffic Present set to True by pedestrian 0000.
	psw	Enter state Red substate Going Green 1.
	pse	Enter state Red substate Going Green 1.
	psw	Enter state Red substate Going Green 2.
	pse	Enter state Red substate Going Green 2.
	psw	Enter state Red substate Going Green 3.
	pse	Enter state Red substate Going Green 3.
	B	Enter state Green substate Looking for Gap 3.
	C	Enter state Green substate Looking for Gap 3.
	F	Enter state Green substate Looking for Gap 3.
	G	Enter state Green substate Looking for Gap 3.
	B	Enter state Yellow substate Going Red.
	B	Set lamp to Steady Circular Yellow.
	C	Enter state Yellow substate Going Red.
	C	Set lamp to Steady Circular Yellow.
	F	Enter state Yellow substate Going Red.
	F	Set lamp to Steady Circular Yellow.
	G	Enter state Yellow substate Going Red.

Table 14: Pedestrian Crosses continued

Time	Lane	Events
	G	Set lamp to Steady Circular Yellow.
203.429	psw	Pedestrian 0000 stopped.
207.858	B	Enter state Red substate Waiting for Clearance.
	B	Set lamp to Steady Circular Red.
	C	Enter state Red substate Waiting for Clearance.
	C	Set lamp to Steady Circular Red.
	F	Enter state Red substate Waiting for Clearance.
	F	Set lamp to Steady Circular Red.
	G	Enter state Red substate Waiting for Clearance.
	G	Set lamp to Steady Circular Red.
208.858	B	Enter state Red substate Travel Path is Clear.
	C	Enter state Red substate Travel Path is Clear.
	F	Enter state Red substate Travel Path is Clear.
	G	Enter state Red substate Travel Path is Clear.
	psw	Enter state Green substate Minimum Green.
	psw	Set lamp to Walk.
	pse	Enter state Green substate Minimum Green.
	pse	Set lamp to Walk.
	psw	Pedestrian 0000 enters the crosswalk.
209.430	psw	Sensor Traffic Present set to False by pedestrian 0000.
214.858	psw	Enter state Green substate Looking for Gap 1.
	pse	Enter state Green substate Looking for Gap 1.
218.858	psw	Enter state Green substate Looking for Gap 2.
	pse	Enter state Green substate Looking for Gap 2.
236.287	pse	Pedestrian 0000 leaves the crosswalk.
239.716	pse	Pedestrian 0000 exits the simulation.
267.858	B	Enter state Red substate Going Green 4.
	C	Enter state Red substate Going Green 4.
	F	Enter state Red substate Going Green 4.
	G	Enter state Red substate Going Green 4.
	B	Enter state Red substate Going Green 5.

Table 14: Pedestrian Crosses continued

Time	Lane	Events
	C	Enter state Red substate Going Green 5.
	F	Enter state Red substate Going Green 5.
	G	Enter state Red substate Going Green 5.
	psw	Enter state Green substate Looking for Gap 3.
	pse	Enter state Green substate Looking for Gap 3.
	psw	Enter state Yellow substate Going Red.
	psw	Set lamp to Walk with Countdown.
	pse	Enter state Yellow substate Going Red.
	pse	Set lamp to Walk with Countdown.
287.858	psw	Enter state Red substate Waiting for Clearance.
	psw	Set lamp to Don't Walk.
	pse	Enter state Red substate Waiting for Clearance.
	pse	Set lamp to Don't Walk.
290.858	psw	Enter state Red substate Travel Path is Clear.
	pse	Enter state Red substate Travel Path is Clear.
	B	Enter state Green substate Minimum Green.
	B	Set lamp to Steady Circular Green.
	C	Enter state Green substate Minimum Green.
	C	Set lamp to Steady Circular Green.
	F	Enter state Green substate Minimum Green.
	F	Set lamp to Steady Circular Green.
	G	Enter state Green substate Minimum Green.
	G	Set lamp to Steady Circular Green.
302.858	B	Enter state Green substate Looking for Gap 1.
	C	Enter state Green substate Looking for Gap 1.
	F	Enter state Green substate Looking for Gap 1.
	G	Enter state Green substate Looking for Gap 1.
350.858	B	Enter state Green substate Looking for Gap 2.
	C	Enter state Green substate Looking for Gap 2.
	F	Enter state Green substate Looking for Gap 2.
	G	Enter state Green substate Looking for Gap 2.

4.10.3 Left Turn

A vehicle arrives at Signal Face A. Assume we are in the idle condition with signal faces B, C, F, and G green and the others red and clear.

Signal face A requests permission to turn green, which it receives right away because no other signal face is requesting permisison to turn green.

Signal face A then causes the Partial Clearance Requested system program to set the Clearance Requested toggle in signal faces psw, pse, D, H, and J.

Signal faces psw, pse, D, H, and J are already clear, so system program Partial Conflicting Paths are Clear sets toggle Partial Conflicting Paths are Clear in signal face A. Notice that signal faces F and G are not clear, so toggle Conflicting Paths are Clear does not get set in signal face A.

Signal face A proceeds to state Yellow substate Flashing 1. The red light at lane A turns to a yellow flashing light, telling the vehicle operator that he may turn left but must watch for oncoming traffic.

When the Left Flashing Yellow Waiting timer completes, if there is still traffic for signal face A it proceeds to substate Going Green where it sets the toggle Request Clearance, causing system program Clearance Requested to set the Clearance Requested toggle in signal faces psw, pse, D, F, G, H, and J.

Signal faces psw, pse, D, H and J are already clear. Signal faces F and G turn yellow, then red, then become clear.

When signal faces F and G become clear system program Conflicting Paths are Clear will set the Conflicting Paths are Clear toggle in signal face A which will cause signal face A to turn green.

When the Vehicle Gone timer in signal face A completes, signal face A will turn red and eventually become clear, which will allow signal faces F and G to turn green when their Red Limit timers complete, as described above.

The following events take place assuming that the driver of the car turning left is not willing to make the permissive turn, and so waits for the green arrow.

Table 15: Left Turn Delayed

Time	Lane	Event
200.000	B	Car 0000 starts on travel path A6 speed 45.0 mph.
201.364	A	Car 0000 leaves lane B.
210.201	A	Sensor Traffic Approaching set to True by car 0000.
	A	Set toggle Traffic Approaching by sensor A/Traffic Approaching.
	A	Enter state Red substate Going Green 1.
	A	Set toggle Request Green.
	A	Set toggle Green Request Granted by system program Green Request Granted.
	A	Enter state Red substate Going Green 2.

Table 15: Left Turn Delayed continued

Time	Lane	Events
	A	Enter state Red substate Going Green 3.
	A	Clear toggle Request Green.
	A	Set toggle Request Partial Clearance.
	A	Set toggle Partial Conflicting Paths are Clear by system program Partial Conflicting Paths are Clear.
	A	Enter state Yellow substate Left Flashing 1.
	A	Set lamp to Flashing Left Arrow Yellow (lower).
	A	Clear toggle Green Request Granted.
	A	Clear toggle Cleared.
	A	Set toggle Traffic Flowing.
210.774	A	Sensor Traffic Approaching set to False by car 0000.
213.446	A	Sensor Traffic Present set to True by car 0000.
	A	Set toggle Traffic Present by sensor A/Traffic Present.
213.637	A	Car 0000 stopped.
215.201	A	Enter state Yellow substate Left Flashing 2.
	A	Clear toggle Traffic Approaching.
225.201	A	Enter state Yellow substate Going Green.
	A	Set toggle Request Clearance.
	F	Set toggle Clearance Requested by system program Clearance Requested.
	G	Set toggle Clearance Requested by system program Clearance Requested.
	F	Enter state Green substate Looking for Gap 3.
	G	Enter state Green substate Looking for Gap 3.
	F	Enter state Yellow substate Going Red.
	F	Set lamp to Steady Circular Yellow.
	G	Enter state Yellow substate Going Red.
	G	Set lamp to Steady Circular Yellow.
230.201	F	Enter state Red substate Waiting for Clearance.
	F	Set lamp to Steady Circular Red.
	G	Enter state Red substate Waiting for Clearance.
	G	Set lamp to Steady Circular Red.

Table 15: Left Turn Delayed continued

Time	Lane	Events
231.201	F	Enter state Red substate Travel Path is Clear.
	F	Set toggle Cleared.
	F	Clear toggle Clearance Requested.
	F	Clear toggle Traffic Flowing.
	G	Enter state Red substate Travel Path is Clear.
	G	Set toggle Cleared.
	G	Clear toggle Clearance Requested.
	G	Clear toggle Traffic Flowing.
	A	Set toggle Conflicting Paths are Clear by system program Conflicting Paths are Clear.
	A	Enter state Green substate Minimum Green.
	A	Set lamp to Steady Left Arrow Green.
	A	Clear toggle Request Partial Clearance.
	A	Clear toggle Request Clearance.
	A	Clear toggle Conflicting Paths are Clear by system program Conflicting Paths are Clear.
	A	Clear toggle Partial Conflicting Paths are Clear by system program Partial Conflicting Paths are Clear.
	A	Car 0000 enters the intersection.
231.583	A	Sensor Traffic Present set to False by car 0000.
233.905	6	Car 0000 leaves the intersection.
236.201	A	Enter state Green substate Looking for Gap 1.
	A	Clear toggle Traffic Present.
246.201	A	Enter state Yellow substate Going Red.
	A	Set lamp to Steady Left Arrow Yellow (upper).
248.305	6	Car 0000 exits the simulation.
249.701	A	Enter state Red substate Waiting for Clearance.
	A	Set lamp to Steady Left Arrow Red.
250.701	A	Enter state Red substate Travel Path is Clear.
	A	Set toggle Cleared.
	A	Clear toggle Traffic Flowing.
290.201	F	Enter state Red substate Going Green 4.

Table 15: Left Turn Delayed continued

Time	Lane	Events
	F	Set toggle Request Green.
	G	Enter state Red substate Going Green 4.
	G	Set toggle Request Green.
	F	Set toggle Green Request Granted by system program Green Request Granted.
	G	Set toggle Green Request Granted by system program Green Request Granted.
	F	Enter state Red substate Going Green 5.
	F	Clear toggle Request Green.
	F	Set toggle Request Partial Clearance.
	G	Enter state Red substate Going Green 5.
	G	Clear toggle Request Green.
	G	Set toggle Request Partial Clearance.
	F	Set toggle Conflicting Paths are Clear by system program Conflicting Paths are Clear.
	G	Set toggle Conflicting Paths are Clear by system program Conflicting Paths are Clear.
	F	Set toggle Partial Conflicting Paths are Clear by system program Partial Conflicting Paths are Clear.
	G	Set toggle Partial Conflicting Paths are Clear by system program Partial Conflicting Paths are Clear.
	F	Enter state Green substate Minimum Green.
	F	Set lamp to Steady Circular Green.
	F	Clear toggle Green Request Granted.
	F	Clear toggle Cleared.
	F	Clear toggle Request Partial Clearance.
	F	Set toggle Traffic Flowing.
	G	Enter state Green substate Minimum Green.
	G	Set lamp to Steady Circular Green.
	G	Clear toggle Green Request Granted.
	G	Clear toggle Cleared.
	G	Clear toggle Request Partial Clearance.
	G	Set toggle Traffic Flowing.

Table 15: Left Turn Delayed continued

Time	Lane	Events
	F	Clear toggle Conflicting Paths are Clear by system program Conflicting Paths are Clear.
	G	Clear toggle Conflicting Paths are Clear by system program Conflicting Paths are Clear.
	F	Clear toggle Partial Conflicting Paths are Clear by system program Partial Conflicting Paths are Clear.
	G	Clear toggle Partial Conflicting Paths are Clear by system program Partial Conflicting Paths are Clear.
302.201	F	Enter state Green substate Looking for Gap 1.
	G	Enter state Green substate Looking for Gap 1.
350.201	F	Enter state Green substate Looking for Gap 2.
	G	Enter state Green substate Looking for Gap 2.

However, if the vehicle makes the permissive left turn, signal face A returns to red, never causing signal faces F and G to turn red, as illustrated in the following events.

Table 16: Left Turn

Time	Lane	Event
200.000	B	Car 0000 starts on travel path A6 speed 45.0 mph.
201.364	A	Car 0000 leaves lane B.
210.201	A	Sensor Traffic Approaching set to True by car 0000.
	A	Set toggle Traffic Approaching by sensor A/Traffic Approaching.
	A	Enter state Red substate Going Green 1.
	A	Set toggle Request Green.
	A	Set toggle Green Request Granted by system program Green Request Granted.
	A	Enter state Red substate Going Green 2.
	A	Enter state Red substate Going Green 3.
	A	Clear toggle Request Green.
	A	Set toggle Request Partial Clearance.
	A	Set toggle Partial Conflicting Paths are Clear by system program Partial Conflicting Paths are Clear.

Table 16: Left Turn continued

Time	Lane	Events
	A	Enter state Yellow substate Left Flashing 1.
	A	Set lamp to Flashing Left Arrow Yellow (lower).
	A	Clear toggle Green Request Granted.
	A	Clear toggle Cleared.
	A	Set toggle Traffic Flowing.
210.774	A	Sensor Traffic Approaching set to False by car 0000.
213.446	A	Sensor Traffic Present set to True by car 0000.
	A	Set toggle Traffic Present by sensor A/Traffic Present.
213.637	A	Car 0000 stopped.
214.637	A	Car 0000 enters the intersection.
215.019	A	Sensor Traffic Present set to False by car 0000.
215.201	A	Enter state Yellow substate Left Flashing 2.
	A	Clear toggle Traffic Present.
	A	Clear toggle Traffic Approaching.
217.341	6	Car 0000 leaves the intersection.
225.201	A	Enter state Yellow substate Going Red.
	A	Set lamp to Steady Left Arrow Yellow (upper).
228.701	A	Enter state Red substate Waiting for Clearance.
	A	Set lamp to Steady Left Arrow Red.
229.701	A	Enter state Red substate Travel Path is Clear.
	A	Set toggle Cleared.
	A	Clear toggle Traffic Flowing.
	A	Clear toggle Request Partial Clearance.
	A	Clear toggle Partial Conflicting Paths are Clear by system program Partial Conflicting Paths are Clear.
231.741	6	Car 0000 exits the simulation.

4.10.4 Pedestrian and Near Left Turner

Building upon the previous two illustrations, suppose after the pedestrian has pushed his button and begun to cross, a vehicle arrives at lane A. Signal face A will be be given permission to turn green right away, since no other signal faces are waiting to turn green. It will then request that signal faces psw, pse, D, H, and J turn red. Signal faces D and J will already be clear because signal faces pse and psw is green, and signal face H has never been green, so signal face A is

waiting only for signal faces psw and pse.

When signal faces psw and pse are clear signal face A will turn green because signal faces F and G are clear due to signal faces psw and pse, so the left turn is protected rather than permissive.

Signal faces B, C, F, and G will want to turn green and so signal faces F and G will ask signal face A to turn red. Signal faces B and C will turn green without waiting for signal face A to clear, since they do not conflict. When signal face A is clear signal faces F and G will turn green, getting us back to the idle state.

Here are the events of this illustration, with less detail than previously.

Table 17: Pedestrian then Left Turn

Time	Lane	Event
200.000	psw	Pedestrian 0000 starts on travel path pswpse speed 03.5 fps.
202.858	psw	Sensor Traffic Present set to True by pedestrian 0000.
	psw	Enter state Red substate Going Green 1.
	pse	Enter state Red substate Going Green 1.
	psw	Enter state Red substate Going Green 2.
	pse	Enter state Red substate Going Green 2.
	psw	Enter state Red substate Going Green 3.
	pse	Enter state Red substate Going Green 3.
	B	Enter state Green substate Looking for Gap 3.
	C	Enter state Green substate Looking for Gap 3.
	F	Enter state Green substate Looking for Gap 3.
	G	Enter state Green substate Looking for Gap 3.
	B	Enter state Yellow substate Going Red.
	B	Set lamp to Steady Circular Yellow.
	C	Enter state Yellow substate Going Red.
	C	Set lamp to Steady Circular Yellow.
	F	Enter state Yellow substate Going Red.
	F	Set lamp to Steady Circular Yellow.
	G	Enter state Yellow substate Going Red.
	G	Set lamp to Steady Circular Yellow.
203.429	psw	Pedestrian 0000 stopped.
205.000	B	Car 0001 starts on travel path A6 speed 45.0 mph.
206.364	A	Car 0001 leaves lane B.
207.858	B	Enter state Red substate Waiting for Clearance.

Table 17: Pedestrian then Left Turn continued

Time	Lane	Events
	B	Set lamp to Steady Circular Red.
	C	Enter state Red substate Waiting for Clearance.
	C	Set lamp to Steady Circular Red.
	F	Enter state Red substate Waiting for Clearance.
	F	Set lamp to Steady Circular Red.
	G	Enter state Red substate Waiting for Clearance.
	G	Set lamp to Steady Circular Red.
208.858	B	Enter state Red substate Travel Path is Clear.
	C	Enter state Red substate Travel Path is Clear.
	F	Enter state Red substate Travel Path is Clear.
	G	Enter state Red substate Travel Path is Clear.
	psw	Enter state Green substate Minimum Green.
	psw	Set lamp to Walk.
	pse	Enter state Green substate Minimum Green.
	pse	Set lamp to Walk.
	psw	Pedestrian 0000 enters the crosswalk.
209.430	psw	Sensor Traffic Present set to False by pedestrian 0000.
214.858	psw	Enter state Green substate Looking for Gap 1.
	pse	Enter state Green substate Looking for Gap 1.
215.201	A	Sensor Traffic Approaching set to True by car 0001.
	A	Enter state Red substate Going Green 1.
	A	Enter state Red substate Going Green 2.
	A	Enter state Red substate Going Green 3.
215.774	A	Sensor Traffic Approaching set to False by car 0001.
215.858	psw	Enter state Yellow substate Going Red.
	psw	Set lamp to Walk with Countdown.
	pse	Enter state Yellow substate Going Red.
	pse	Set lamp to Walk with Countdown.
218.446	A	Sensor Traffic Present set to True by car 0001.
218.637	A	Car 0001 stopped.
235.858	psw	Enter state Red substate Waiting for Clearance.

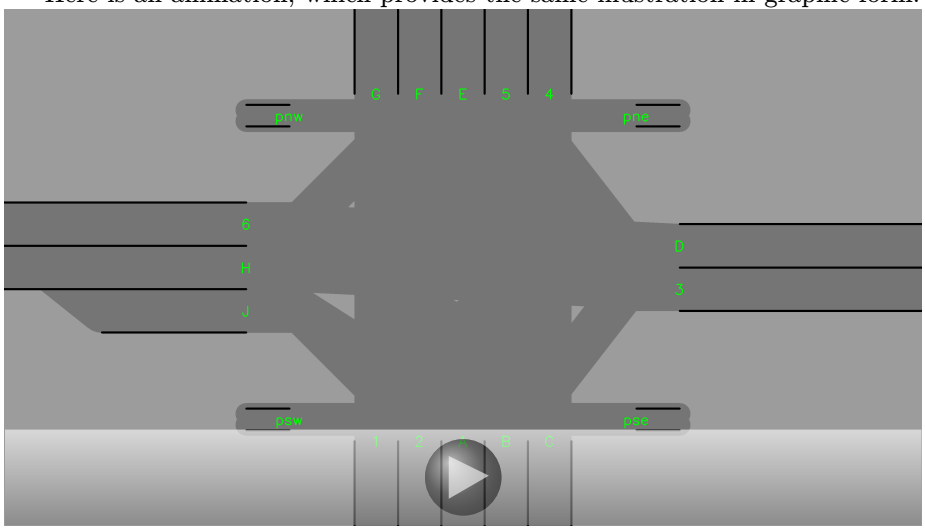
Table 17: Pedestrian then Left Turn continued

Time	Lane	Events
	psw	Set lamp to Don't Walk.
	pse	Enter state Red substate Waiting for Clearance.
	pse	Set lamp to Don't Walk.
236.287	pse	Pedestrian 0000 leaves the crosswalk.
238.858	psw	Enter state Red substate Travel Path is Clear.
	pse	Enter state Red substate Travel Path is Clear.
	A	Enter state Green substate Minimum Green.
	A	Set lamp to Steady Left Arrow Green.
	A	Car 0001 enters the intersection.
239.240	A	Sensor Traffic Present set to False by car 0001.
239.716	pse	Pedestrian 0000 exits the simulation.
241.562	6	Car 0001 leaves the intersection.
243.858	A	Enter state Green substate Looking for Gap 1.
253.858	A	Enter state Yellow substate Going Red.
	A	Set lamp to Steady Left Arrow Yellow (upper).
255.962	6	Car 0001 exits the simulation.
257.358	A	Enter state Red substate Waiting for Clearance.
	A	Set lamp to Steady Left Arrow Red.
258.358	A	Enter state Red substate Travel Path is Clear.
267.858	B	Enter state Red substate Going Green 4.
	C	Enter state Red substate Going Green 4.
	F	Enter state Red substate Going Green 4.
	G	Enter state Red substate Going Green 4.
	B	Enter state Red substate Going Green 5.
	C	Enter state Red substate Going Green 5.
	F	Enter state Red substate Going Green 5.
	G	Enter state Red substate Going Green 5.
	B	Enter state Green substate Minimum Green.
	B	Set lamp to Steady Circular Green.
	C	Enter state Green substate Minimum Green.
	C	Set lamp to Steady Circular Green.

Table 17: Pedestrian then Left Turn continued

Time	Lane	Events
	F	Enter state Green substate Minimum Green.
	F	Set lamp to Steady Circular Green.
	G	Enter state Green substate Minimum Green.
	G	Set lamp to Steady Circular Green.
279.858	B	Enter state Green substate Looking for Gap 1.
	C	Enter state Green substate Looking for Gap 1.
	F	Enter state Green substate Looking for Gap 1.
	G	Enter state Green substate Looking for Gap 1.
327.858	B	Enter state Green substate Looking for Gap 2.
	C	Enter state Green substate Looking for Gap 2.
	F	Enter state Green substate Looking for Gap 2.
	G	Enter state Green substate Looking for Gap 2.

Here is an animation, which provides the same illustration in graphic form.



If your PDF viewer will not play the animation you can see it on Youtube at this URL: https://youtu.be/RBuMvScOgxk.

4.10.5 Multiple Arrivals

Suppose we are in the Idle condition when traffic arrives in quick succession at signal faces A, psw, D, E, pne, H, and J in that order.

Signal face A turns left flashing yellow immediately since lanes F and G are allowing traffic to flow.

Signal face psw asks signal faces A, B, C, F, and G to turn red. Signal face A is currently left flashing yellow but signal faces B, C, F, and G turn yellow and then red.

With the through lanes all stopped signal face A turns green, then yellow, then red, permitting the pedestrians in the south crosswalk to cross. Signal face E does the same, permitting the pedestrians in the north crosswalk to cross.

When the pedestrians in the south crosswalk have crossed, signal face J turns green. Similarly, when the pedestrians in the north crosswalk have crossed, signal face H turns green.

When signal faces H and J have turned red, signal face D can finally turn green. When it turns red signal faces B, C, F, and G turn green, getting us back to the idle state.

To summarize, if traffic arrives in quick succession on signal faces A, psw, D, E, pne, H and J, traffic will flow through signal faces A and E, then through psw and pne, then H and J, and finally D.

The following table shows the most significant events in this scenario.

Table 18: Many Events

Time	Lane	Event
200.000	D	Car 0000 starts on travel path D6 speed 25.0 mph.
203.000	B	Car 0001 starts on travel path A6 speed 45.0 mph.
204.000	H	Truck 0002 starts on travel path H5 speed 25.0 mph.
204.364	A	Car 0001 leaves lane B.
205.000	F	Car 0003 starts on travel path E3 speed 45.0 mph.
206.000	H	Car 0004 starts on travel path J1 speed 25.0 mph.
206.364	E	Car 0003 leaves lane F.
211.000	psw	Pedestrian 0005 starts on travel path pswpse speed 03.5 fps.
213.201	A	Sensor Traffic Approaching set to True by car 0001.
	A	Set lamp to Flashing Left Arrow Yellow (lower).
213.774	A	Sensor Traffic Approaching set to False by car 0001.
213.858	psw	Sensor Traffic Present set to True by pedestrian 0005.
	B	Set lamp to Steady Circular Yellow.
	C	Set lamp to Steady Circular Yellow.
	F	Set lamp to Steady Circular Yellow.
	G	Set lamp to Steady Circular Yellow.
214.000	pne	Pedestrian 0006 starts on travel path pnepnw speed 03.5 fps.
214.210	D	Sensor Traffic Present set to True by car 0000.
214.400	D	Car 0000 stopped.

Table 18: Many Events continued

Time	Lane	Events
214.429	psw	Pedestrian 0005 stopped.
215.201	E	Sensor Traffic Approaching set to True by car 0003.
	E	Set lamp to Flashing Left Arrow Yellow (lower).
215.774	E	Sensor Traffic Approaching set to False by car 0003.
216.446	A	Sensor Traffic Present set to True by car 0001.
216.637	A	Car 0001 stopped.
216.858	pne	Sensor Traffic Present set to True by pedestrian 0006.
217.429	pne	Pedestrian 0006 stopped.
217.637	A	Car 0001 enters the intersection.
218.019	A	Sensor Traffic Present set to False by car 0001.
218.210	H	Sensor Traffic Present set to True by truck 0002.
218.400	H	Truck 0002 stopped.
218.446	E	Sensor Traffic Present set to True by car 0003.
218.637	E	Car 0003 stopped.
218.858	B	Set lamp to Steady Circular Red.
	C	Set lamp to Steady Circular Red.
	F	Set lamp to Steady Circular Red.
	G	Set lamp to Steady Circular Red.
219.424	J	Car 0004 leaves lane H.
219.637	E	Car 0003 enters the intersection.
219.858	A	Set lamp to Steady Left Arrow Green.
220.019	E	Sensor Traffic Present set to False by car 0003.
220.201	E	Set lamp to Steady Left Arrow Green.
220.325	J	Sensor Traffic Present set to True by car 0004.
220.341	6	Car 0001 leaves the intersection.
220.515	J	Car 0004 stopped.
222.257	3	Car 0003 leaves the intersection.
226.758	A	Set lamp to Steady Left Arrow Yellow (upper).
227.101	E	Set lamp to Steady Left Arrow Yellow (upper).
230.258	A	Set lamp to Steady Left Arrow Red.
230.601	E	Set lamp to Steady Left Arrow Red.

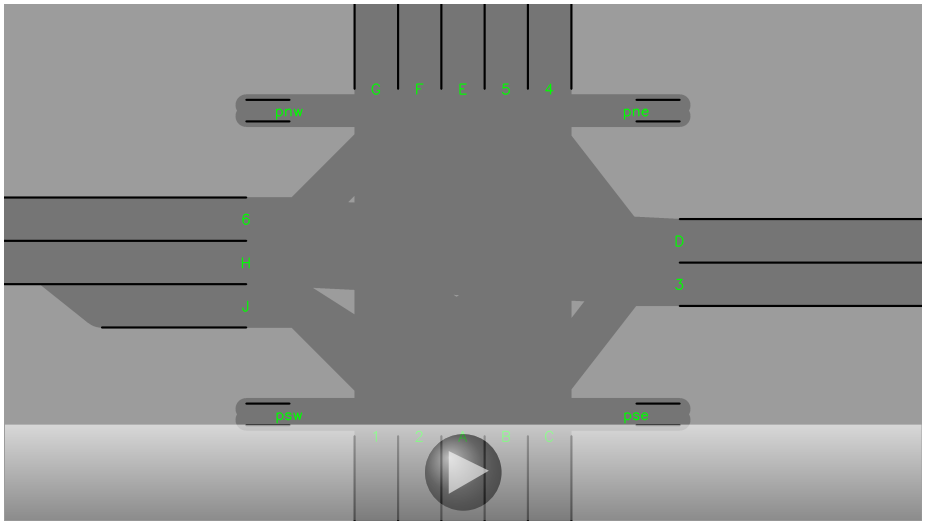
Table 18: Many Events continued

Time	Lane	Events
231.258	psw	Set lamp to Walk.
	pse	Set lamp to Walk.
	psw	Pedestrian 0005 enters the crosswalk.
231.601	pnw	Set lamp to Walk.
	pne	Set lamp to Walk.
	pne	Pedestrian 0006 enters the crosswalk.
231.830	psw	Sensor Traffic Present set to False by pedestrian 0005.
232.173	pne	Sensor Traffic Present set to False by pedestrian 0006.
234.741	6	Car 0001 exits the simulation.
236.657	3	Car 0003 exits the simulation.
238.258	psw	Set lamp to Walk with Countdown.
	pse	Set lamp to Walk with Countdown.
238.601	pnw	Set lamp to Walk with Countdown.
	pne	Set lamp to Walk with Countdown.
258.258	psw	Set lamp to Don't Walk.
	pse	Set lamp to Don't Walk.
258.601	pnw	Set lamp to Don't Walk.
	pne	Set lamp to Don't Walk.
258.687	pse	Pedestrian 0005 leaves the crosswalk.
259.030	pnw	Pedestrian 0006 leaves the crosswalk.
261.258	J	Set lamp to Steady Right Arrow Green.
	J	Car 0004 enters the intersection.
261.601	H	Set lamp to Steady Left Arrow Green and Steady Circular Green.
	H	Truck 0002 enters the intersection.
261.640	J	Sensor Traffic Present set to False by car 0004.
262.116	pse	Pedestrian 0005 exits the simulation.
262.459	pnw	Pedestrian 0006 exits the simulation.
262.610	H	Sensor Traffic Present set to False by truck 0002.
262.888	1	Car 0004 leaves the intersection.
264.477	5	Truck 0002 leaves the intersection.
270.158	J	Set lamp to Steady Right Arrow Yellow.

Table 18: Many Events continued

Time	Lane	Events
270.501	H	Set lamp to Steady Circular Yellow.
270.889	1	Car 0004 exits the simulation.
272.478	5	Truck 0002 exits the simulation.
273.158	J	Set lamp to Steady Right Arrow Red.
273.501	H	Set lamp to Steady Circular Red.
275.001	D	Set lamp to Steady Circular Green.
	D	Car 0000 enters the intersection.
275.387	D	Sensor Traffic Present set to False by car 0000.
278.278	6	Car 0000 leaves the intersection.
283.901	D	Set lamp to Steady Circular Yellow.
286.901	D	Set lamp to Steady Circular Red.
288.401	B	Set lamp to Steady Circular Green.
	C	Set lamp to Steady Circular Green.
	F	Set lamp to Steady Circular Green.
	G	Set lamp to Steady Circular Green.
292.678	6	Car 0000 exits the simulation.

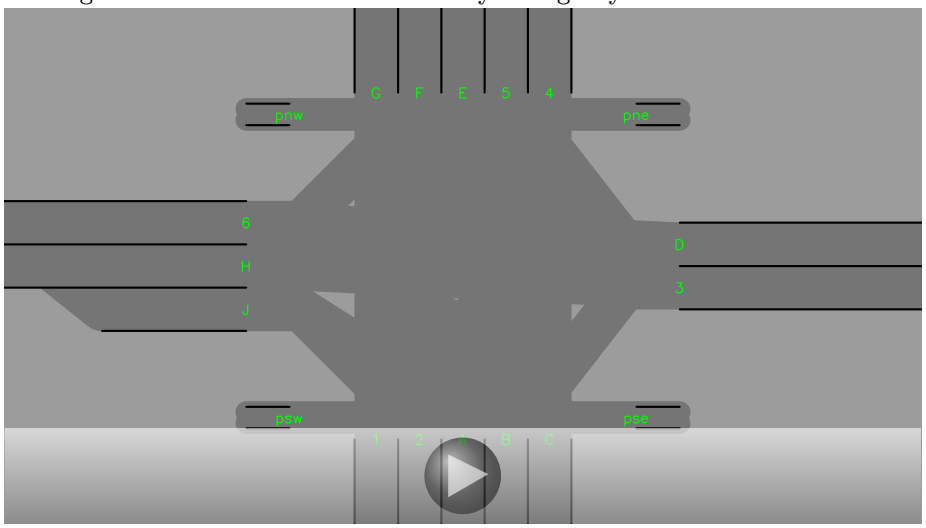
Here is an animation of the multiple arrivals scenario:



If your PDF viewer will not play the animation you can see it on Youtube at this URL: https://youtu.be/DCo7ZpW0FQg.

4.10.6 Heavy Traffic

To illustrate how the traffic control signal handles heavy traffic, here is an animation showing traffic arriving from all directions, and the intersection flashing for a few seconds due to a nearby emergency vehicle.



If your PDF viewer will not play the animation you can see it on Youtube at this URL: https://youtu.be/6oFNbIGWkH4.

5 Manual Control

An operator may take manual control of the traffic control signal. The operator's control panel contains the following controls:

5.1 Off Switch

The Off switch turns off power to the traffic control signal and all of the signal faces. Turning off power is necessary for safety during maintenance.

5.2 Mode

There is a multi-position mode switch:

5.2.1 Automatic

With the mode switch set to Automatic the traffic control signal processes signals from the sensors and acts appropriately, as described above. The operator is an observer who can see the color of each signal face, the state of the toggle corresponding to each vehicle detector, and the names of the signal faces in each persistent list maintained by the Green Request Granted system program.

The operator can choose to also see the state and substate of each signal face, the state of each timer, the time until completion of each running timer, and the state of each toggle and sensor.

5.2.2 Manual

With the mode switch set to Manual, the traffic control signal is not responsive to the sensors. The operator has a 3-position switch on the display of each lane to cause that lane to turn red or green. The Red position sets the Manual Red toggle and the green position sets the Manual Green toggle. The third position is neutral, which sets neither toggle.

In this mode, as in Automatic mode, the operator sees the state of each signal face and each vehicle detector. Also as in Automatic mode, the operator can choose to also see the substate of each signal face, the state of each timer, the time until completion of each running timer, and the state of each toggle.

In this mode the operator must specify when each signal face turns red and green. Notice that all of the safety interlocks still are in effect: setting a signal face to green while a conflicting signal face is already set to green will have no effect until the conflicting signal faces are set to red or neutral. There is an option in the manual control panel to automatically set all conflicting signal faces to red when a signal face is manually set to green.

A manual control panel can be either local or remote. If it is remote there should be cameras giving a complete picture of the intersection to the remote operator.

5.2.3 Flashing

With the mode switch set to Flashing, each signal face will turn red as quickly as possible consistent with safety, and then flash either red or yellow.

If the traffic signal controller detects a malfunction it switches to Flashing mode itself. In addition, if the computer in the traffic signal controller fails there is hardware in the traffic signal controller to flash the lights independent of the computer, though in this case it will not be possible to first turn the signal face red safely.

5.2.4 Programming

This mode is protected so only authorized persons can access it. It works the same as Automatic mode except the operator is also allowed to adjust the duration of the timers in each signal face, and update the Signal Conflict Table and the Partial Signal Conflict Table.

These adjustments can cause unsafe conditions and so should be limited to highly trusted personnel.

6 Central Control

The signaling procedure described here takes only the traffic at a single intersection into account. Where there are many intersections close together it will be worthwhile to control them all as a single system. In such a control system a central controller will provide overall coordination while each intersecton operates as described here except as directed by the central controller.

The algorithm used by the central controller is beyond the scope of this description, but from the point of view of an individual intersection the central controller will use the Manual Green toggle to clear paths through several intersections so that traffic can flow freely in the chosen directions.

The central controller will be able to see all of the sensors of all of the intersections it controls.

7 More Details

If you would like more details about how a traffic control signal works, you can examine the software used to prepare the tables and animations for this paper. The software is on github at this URL:

https://github.com/JohnSauter/How_Traffic_Control_Signals_Work

That github repository includes a spec file to facilitate building this paper using COPR. That spec file is also included in the tarball.

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References

[1] *Manual on Uniform Traffic Control Devices for Streets and Highways (MUTCD)*. Federal Highway Administration, 11th edition, December 2023. URL `https://mutcd.fhwa.dot.gov/kno_11th_Edition.htm`. 2

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