Traffic Signal Primer

The traffic signal is a device that virtually every citizen encounters on a daily basis. We put our trust in their ability to allow us safe passage through an intersection and we have the expectation that they will serve us efficiently. We may all have some idea of how a signal functions: the order in which it allows movement, the ability for it to be coordinated with other signals, the location we have to stop to let the signal know we are waiting. What may not be readily apparent is how the signal does all of these things and what is really going on inside that big box you see beside every signalized intersection. The purpose of this primer is not only to answer these questions, but to also acquaint you with how the city is working to provide you reliability, safety, and efficiency at all of its signalized intersections.

The Signal Cabinet

The best place to start learning about a signal is inside its control cabinet. Adjacent to every traffic signal is a cabinet containing the hardware used to control all operational aspects of the signal. The cabinet and the hardware it contains may vary slightly from cabinet to cabinet, but the general function of each is the same. Let's take a look inside a standard City traffic signal cabinet (Figure 1).

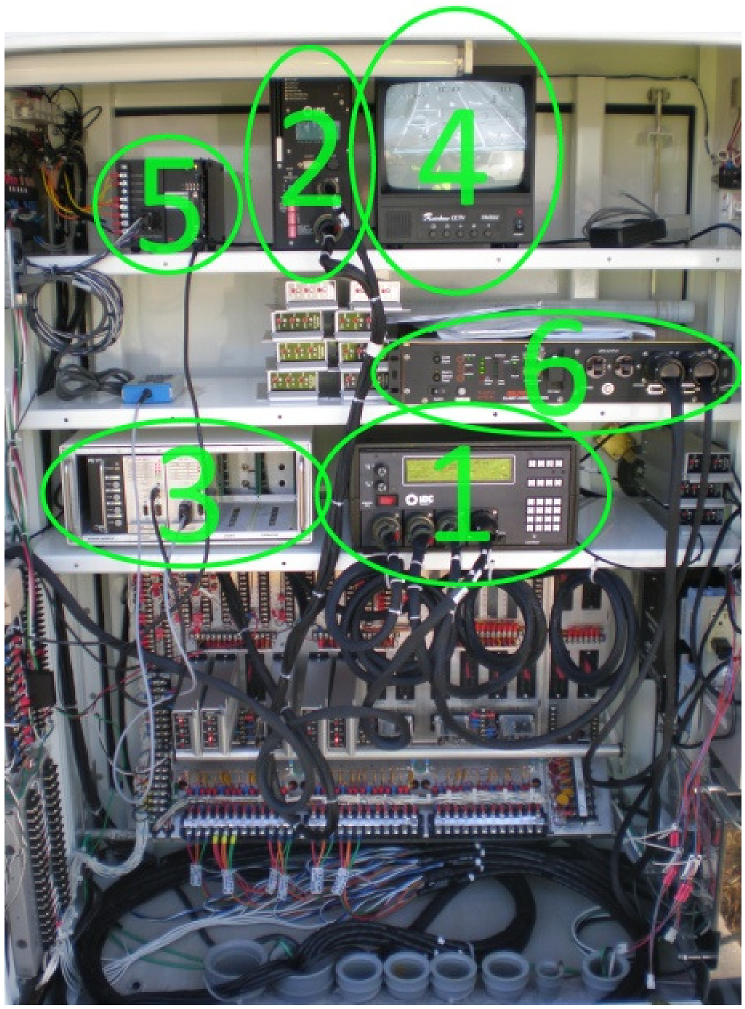

Figure 1. Traffic signal cabinet

The primary components inside the cabinet have been circled and labeled and are named as follows:

1) Traffic Signal Controller
2) Conflict Monitor
3) Video Detection Card Rack
4) Video Detection Monitor
5) Emergency Preemption Controller
6) Uninterrupted Power Supply (UPS) Backup

Each of these components plays an integral role in the programming, function, and upkeep of a traffic signal. Details about each of these components are as follows:

1) *Traffic Signal Controller*
The traffic signal controller is the brain of every traffic signal. It contains all of the programming information necessary for the proper functioning of the signal. Information such as green, yellow, and red timings for each movement, emergency and/or railroad preemption programming, and coordination plan timings are all stored in this device. Signals are sent out from the traffic controller to change the signal's lights.

2) *Conflict Monitor*
Every outgoing command sent from the controller is checked by the conflict monitor. The device is hard-wired to prevent conflicting movements from being sent to the signal's lights in the event of a controller malfunction. If there is a problem with a controller, the monitor itself, or if signal light wiring is removed or damaged, the conflict monitor automatically puts the signal into flash mode until the issue is resolved. The monitors are tested annually (along with all other cabinet components) to ensure their proper operation.

3) *Video Detection Card Rack*
Just about every signal in the City utilizes cameras to detect the presence of vehicular and bicycle traffic (Figure 2). Each camera brings a live video feed back to the signal's cabinet, which is fed through the video detection card rack and can be viewed on the monitor. The video detection cards contain firmware (software inside the card itself) that is used to program detection 'zones'. These zones activate when the image of a vehicle or a bicycle enters the zone (Figure 3). When the zone activates, a 'call' is sent to the traffic controller telling it that there is something present at the particular movement to which the zone was assigned. In order to be detected by the camera, you must stop at the stop bar in the middle of the lane. Bicyclists should approach a red light in the middle of the travel lane in order to be detected.

Figure 2. Video detection camera

4) *Video Detection Monitor*

The video detection monitor (Figures 1 and 3) is used to check the quality of the video feed and to program the video detection cards. Since camera detection can be influenced by factors such as glare, fog, and extreme weather conditions, these monitors become essential in determining the best positioning and configuration of the camera detection system.

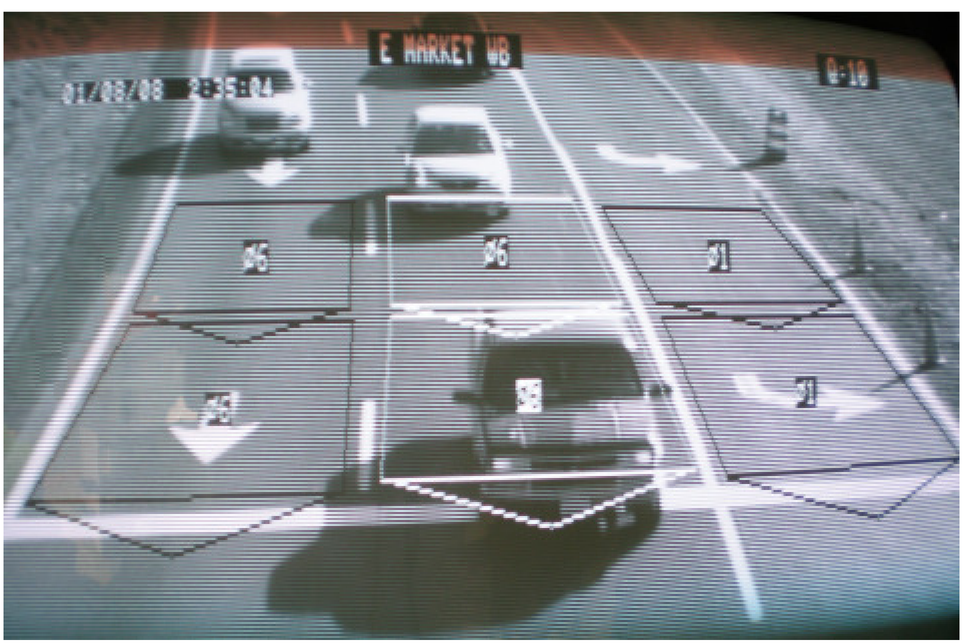

Figure 3. Video detection monitor displaying detection zones

5) *Emergency Preemption Controller*

Several signalized intersection in the City are equipped with an emergency preemption system that allows for faster and safer travel of emergency vehicles through a signal. Emergency vehicles are equipped with an emitter that sends a transmission to a receiver installed on the signal's mast arm (figure 4). When activated, the receiver sends a signal to the traffic controller, which is programmed to give priority to the approaching emergency vehicle. Examples of the system can be seen on East Market Street and Reservoir Street.

Figure 4. Emergency preemption system (3M™)

6) *Uninterrupted Power Supply (UPS) Backup*

The City is working on equipping many signals with an Uninterrupted Power Supply (UPS) backup. In the event of a power loss, the systems instantly transition to emergency power to keep the signal in operation.

Signal Phasing and Operation Modes

To move everyone through the intersection in an orderly and safe manner, traffic signals service each movement at an intersection using a structured system of 'phases'. A phase is a movement at an intersection that has no conflict with any other movement. A phase is typically assigned to each through movement and each left turn at an intersection. The traffic controller and conflict monitor are programmed to only allow a green indication at non-conflicting phases. In general, a maximum of two of these phases can be green simultaneously and the phases must come up in the order in which they are programmed.

Traffic controllers are programmed to cycle through the phases of the intersection using a set of timings given to each phase. These timings can function a little differently depending upon whether the intersection is capable of vehicle detection. To understand how these timings work, one must first know the different 'modes' in which a signal can function. Traffic signal phase changes can be based on one of the following three systems: pre-timed, semi-actuated, or fully-actuated. Actuation is the detection of vehicle presence, whether it be through cameras, ground 'loops', or another method. If the signal is keeping track of where you are waiting, then it is actuated.

Pre-Timed Operation:

In pre-timed operation, no detection is used at the signal. In this operation mode, the phases are assigned a set order and amount of time that is not dependent upon vehicle presence. The best example of the use of pre-timed operation can be seen in the downtown area on Main Street and Liberty Street. In general, if there are no cameras or ground loops present at an intersection, then it is running in pre-timed mode.

Semi-Actuated Operation:

Semi-actuated operation uses detection only for certain phases (or movements) at the intersection. In Harrisonburg, this system of operation is almost exclusively used for coordinated systems during periods of heavy volume.

Fully-Actuated Operation:

As indicated by its name, fully-actuated means that vehicle detection is enabled for all phases at the intersection. This system of operation is what the great majority of traffic signals in Harrisonburg use.

Signal Timing

For phases that are actuated in either semi- or fully-actuated operation, a 'call' will be sent to the traffic controller alerting it that your phase needs to be serviced. When serviced, each phase uses its programmed timings, which are comprised of several components: minimum green, maximum green, yellow, red, gap, pedestrian walk, and pedestrian clearance times.

Each phase that is serviced must be given its minimum green time, which is typically about 7 seconds. So long as calls (or vehicle actuations) continue to be sent to the controller, it will count down the maximum time after the minimum time is used. The maximum green time is dependent upon the amount of traffic the phase typically receives and the amount of delay it may cause for other movements. The maximum time will keep counting down unless there is a 'gap', or space in traffic. Typically, the gap time is set at 3 seconds, meaning that the signal will change if no vehicles are detected for 3 seconds.

If no vehicles are present at an actuated intersection, the signal is programmed to 'recall', or revert, to the 'main street' phase, or the phase that is typically the busiest. Actuated signals will always give the minimum green time to the main street phase(s) regardless of vehicle presence and will hold in the phase(s) until traffic is detected on a side street.

Coordination

Many of the traffic signals along major corridors in the City communicate with each other through hard-wire connections or radio communications. These systems are tied in with a master controller that "talks" to multiple signalized intersections, allowing them to be coordinated with one another. For instance, the signals on Route 42 all the way from Wal-Mart to 3rd Street are tied into a master controller that manages coordination for all of the signals when programmed to do so.

In its most basic form, coordination is a way of programming each signal to turn green at a set time for its coordinated phases. The controllers in a coordinated system do this by running the same ‘cycle length’ at each intersection and by using 'offsets' that tell the signals when to turn green in their cycle. A cycle length is the combination of the maximum times given to each phase at an intersection. This can also be seen as the time it takes for the lights on one street at an intersection to go from green to yellow to red and back to green. Each phase may have a different amount of time assigned to it, but the controller will always know where it is in the cycle length.

To know when in the cycle to turn green, each signal's traffic controller is programmed with an ‘offset’. The best coordination plans will utilize these offsets to keep traffic bunched up into large groups in each coordinated direction, allowing them to progress through each signal efficiently without the need for excessive side street delay. On a one-way street with pre-timed signals, such as in the downtown area, this is rather simple since the signals will always follow a set timing plan. Two-way coordinated streets, on the other hand, are entirely different, as they must deal with groups of vehicles coming from both directions at different times as well as variable amounts time needed to service the side streets. While it would be possible to provide excellent progression in a single direction, the other direction would essentially be swimming up-stream, hitting a red light at almost every signal. For this reason, a balance must be found that accomodates both directions.

Since the groups traveling in opposing directions on a two-way coordinated street will not always reach each intersection at the same time, coordinated signals typically function in semi-actuated mode. In this mode, the coordinated phase(s) do not detect vehicles for the coordinated movement and will always hold for their maximum amount of time. This allows both coordinated directions to make it to the intersection while it is green despite any gaps between their arrivals. In larger systems, you may see a signal allow one coordinated direction through, then change to green for the side streets, then come back to service the other coordinated direction.

When coordinating signals, there is often a balancing act that takes place between the quality of progression on the coordinated street and the amount of delay on the side street. The key is choosing the appropriate cycle length and offsets, which is often very difficult due to varying amounts of traffic. With short cycle lengths, the signal cycles often creating a lot of 'lost time', or time that is spent in yellow and red and initial startup delay when a light turns green. Shorter cycles mean less delay on the side streets, but allow much less traffic to get through on the coordinated street.

With increases in cycle length, the amount of green time increases; however, the lost time is experienced less often since there is the same amount of lost time in each cycle. Since there is less lost time with longer cycle lengths, the 'capacity' is greater, meaning that more cars can pass through the intersection each cycle. The downside of longer cycles is that, since there is more green time, there is also more red time. If the cycle length is too long, long lines of cars can form on the side streets since the time they must wait at the signal is increased.

Sometimes, side streets are also coordinated, which adds yet another trade-off. Main street progression, side street progression, capacity, and delay all need to be balanced. With all of these considerations, coordination is a highly complex task. The Transportation Management Program manages all signal timing and coordination plans for the City of Harrisonburg. Using traffic studies and computer modeling and simulation, the team works to balance all of the factors involved in coordination to create efficient plans for signal operation. For more imformation on the Transportation Management Program, please visit the Signal Timing & Coordination page.

Figure 5. Coordination on Port Republic Rd

Delayed Green Arrows

Have you recently driven on Port Republic Rd, East Market St, or Main St, tried to make a left turn at a light, and wondered “did that light just skip my turn?”, then found that the green arrow is serviced after the green ball for the through movement has turned red? You may have also noticed the new signs that read: “Delayed Green Arrow” (Figure 6). At the typical signal in Harrisonburg, left turn arrows come up before the through movement in the cycle. At select intersections, models show that the majority of vehicles approaching the signal would experience significantly less delay if this order were to be reversed. This form of left turn sequencing is also known as a 'lagging left'.

Lagging left turns are a tool used to improve coordination and reduce delay. At intersections where lagging lefts are beneficial, progression of the coordinated movement can be improved significantly by not having to wait for the left turn arrow. Another benefit of lagging lefts is that they allow the left turn arrow to be skipped entirely if all left turns can be made during the permissive green (aka, the green ball). The time that would have been used for the left turn can then be distributed to other movements that need the extra green time.

But what about the vehicle wanting to turn left? When there are openings in oncoming traffic, the vehicles turning left can turn with the “yield on green”, or should it find no breaks in traffic, the signal will know that it has been waiting, and at the end of the green ball, it will stop oncoming traffic with a red light and provide a green arrow. Regardless, the vehicle will have an opportunity to safely turn.

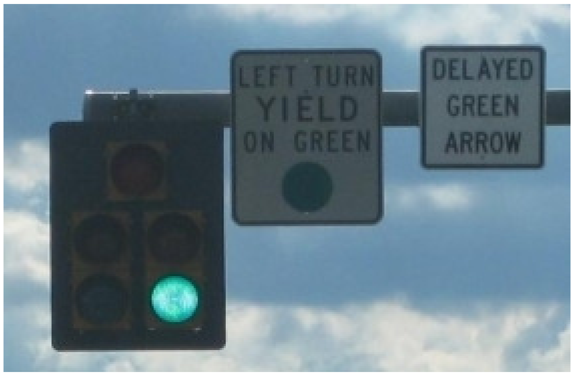

Figure 6. 'Delayed Green Arrow' sign

If you have any suggestions or concerns about a traffic signal, please complete a Signal Service Request or call the Public Works Department at (540) 434-5928.