Improving Intersection Efficiency with Optimally Sized Detection Zones

The benefits of using long detection zones for stop bar vehicle detection have been generally accepted for many years, but problems in the implementation of long loop detectors have prevented the widespread adoption of the detection methodology. The introduction of SmartSensor Matrix as a stop bar presence detector, however, has made the use of long detection zones both possible and practical.

Both the *Traffic Signal Timing Manual* and the *Traffic Detector Handbook* describe the benefits of using long detection zones for stop bar vehicle detection. However, they also describe the problems inherent in using long loop detectors.

Detection at an intersection informs the signal controller that a user desires service. Detectors place calls into the traffic signal controller and the controller uses this information and the signal timing to determine the traffic signal display that the users see. The size and location of detectors is an important element in traffic signal design.

The *Traffic Detector Handbook* states that “when long loops are used in approaches, . . . the passage time intervals are generally set to zero or near zero” (TDH p. 4-4; see also p. 4-17 through 4-18). The *Traffic Signal Timing Manual* also discusses the use of long detection zones with short passage times for improved intersection efficiency (TSTM p. 4-27). However, both documents describe the problems associated with the use of long loops: they may be cost prohibitive, the detection of smaller vehicles is compromised, and false detections from vehicles in adjacent lanes are more likely (TDH p. 4-17 and 4-19, TSTM p. 4-27).

This application note explores the use of a long detection zone at the stop bar to achieve short passage times. The use of the SmartSensor Matrix corner radar presence detector as the vehicle detector in this application is also proposed.

**Passage Time**

Passage time—sometimes called vehicle extension, passage gap or unit extension—is used to extend the green interval based on the detector status once the phase is green. This parameter extends the green interval for each vehicle actuation up to the maximum green time. It begins timing when the vehicle actuation is removed. Research has shown that the passage time interval is one of the most important actuated controller settings.

The passage time is typically set between two and three seconds. With the design proposed in this application note, the passage time can be reduced to between 0.5 and 1 second.

**The Detection Design**

The illustration below shows the detection zones that are used in the detection design described in this application note. The use of the zones for the different phasings is described in the following sections.
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Through Phasing

For the through phasing, the detection should be configured to detect vehicles in any of the through lanes that are within 65 feet of the stop bar, as shown by the detection zones labeled Z1 and Z2 in Figure 1. The output of these detection zones should be mapped in the controller to call and extend the through phase. The passage time should be between 0.5 and 1 second; a passage time of 0.5 seconds should be used for intersections with speeds of 0–25 mph and a passage time of 1 second should be used for intersections with speeds of 30 mph and greater.
With the SmartSensor Matrix, the through lane detection can be accomplished by creating a single detection zone that covers all through lanes as shown in Figure 2.

**Protected/Permissive Left Hand Turn Phasing**

When a protected/permissive left hand turn phase is used, two detection zones are used in the left hand turn lane or lanes as shown by the detection zones labeled Z3 and Z4 in Figure 1. The Z4 detection zone is 15 feet long with the leading edge 50 feet behind the stop bar. A delay of 2–3 seconds is used with this zone so that it will only create a call when the queue in the left hand turn lane extends back to the location of the zone. The output of this zone is used to call and extend the left hand turn phase and the passage time is set to 2–3 seconds.

The Z3 detection zone is configured so that it extends from a few feet in front of the stop bar to 50 feet behind the stop bar. This zone is mapped in the controller to call and extend the through phase with a passage time of 0.5 seconds.

**Protected Only Left Hand Turn Phasing**

When a protected only left hand turn phase is used, the detection for this phase can be accomplished using only the Z3 detection zone that extends from a few feet in front of the stop bar to 50 feet behind the stop bar. The output of this detection zone should be mapped to call and extend the left hand turn phase and the passage time should be set to 0.5 seconds.

**Right Turn Lanes**

Most of the time detection is not needed in the right turn lane. If the right turn lane is the dominant movement for the approach, then detection may be needed and it can be implemented using the same detection zone sizes and passage times as the through lanes.

**Design Advantages**

The design described above has three primary advantages: reduced passage time, reduced vehicle delay and inherent gap reduction. These advantages will be discussed in the following sections.

### Reduced Passage Time

Detection utilizing short detection zones requires a gap out time of 2–3 seconds to ensure that the phase does not gap out while a queue is still dissipating or while traffic is still flowing near saturation. The use of a long detection zone, however, ensures that a call will be placed if a queue still exists or if traffic is near saturation. Thus, if a call is not being placed by the long detection zone then gap out would be appropriate. On page 4-18 of the *Traffic Detector Handbook* the study "Optimal Timing Settings and Detector Lengths of Presence Mode Full-Actuated Control" by Lin, F.-B. is cited. The optimal passage times, as cited from that study, are summarized in the following table:

<table>
<thead>
<tr>
<th>Loop Size (ft)</th>
<th>Passage Time (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30.0</td>
<td>2.0</td>
</tr>
<tr>
<td>50.0</td>
<td>1.0</td>
</tr>
<tr>
<td>80.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

**Table 1 - Passage Time for Various Loops Sizes**

A minimum passage time of 0.5 seconds is recommended to prevent momentary detection drop outs from causing a gap out.

### Reduced Vehicle Delay

The main benefit of short passage times is an overall reduction in vehicle delay. Vehicle delay in passage time is evident at the end
of each phase when the last vehicle in the queue that maintains an acceptable gap leaves the detection zone at the stop bar and extends the passage time for another interval when there are no vehicles maintaining an acceptable gap behind this last vehicle.

For example, if the passage time is reduced by two seconds as proposed in this application note (i.e. 2.5 seconds reduced to 0.5 seconds) and the traffic timing operates on a 120-second cycle, 24 hours a day, 365 days a year, then 146 hours of delay would be saved each year by a single vehicle waiting on another approach of the intersection. The TTI Urban Mobility Report estimates delay to be $15.47 per person per hour, resulting in a delay savings in dollars to one person waiting at the intersection of approximately $2,200 per year. Since there is likely to be on average more than one vehicle waiting on other approaches, the delay savings may be significantly greater. The delay savings can be further compounded by each phase at the intersection where the passage times have been reduced.

**Inherent Gap Reduction**

Gap reduction provides a way to reduce the allowable gap over time, essentially becoming more aggressive in looking for an opportunity to end the phase. The gap reduction feature reduces the passage time to a smaller value while the phase is green. Gap reduction may be desirable when the phase volume is high and it is difficult to differentiate between the end of the initial queue and of the subsequent arrival of randomly formed platoons. This feature allows the user to specify a higher passage time at the beginning of the phase and then incrementally reduce the passage time as a phase gets longer and the delay to conflicting movements increases.

Another benefit of gap reduction occurs on approaches with a steep uphill grade that make it difficult for vehicles to maintain short gaps at the start of the green, and on approaches with many large trucks that have a difficult time maintaining short gaps when accelerating. In these scenarios, the longer passage time at the start of the green will prevent premature gap-outs from occurring.

A large detection zone, as described in this document, has inherent gap reduction, and thus eliminates the need for the programming of the volume density settings in the controller. For example, the following table shows the effective minimum gap that a 65-foot continuous detection zone creates:

<table>
<thead>
<tr>
<th>Speed (mph)</th>
<th>Vehicle Gap for Detection Dropout (sec)</th>
<th>Passage Time (sec)</th>
<th>Effective Min Gap (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>4.4</td>
<td>0.5</td>
<td>4.9</td>
</tr>
<tr>
<td>15</td>
<td>3.0</td>
<td>0.5</td>
<td>3.5</td>
</tr>
<tr>
<td>20</td>
<td>2.2</td>
<td>0.5</td>
<td>2.7</td>
</tr>
<tr>
<td>25</td>
<td>1.8</td>
<td>0.5</td>
<td>2.3</td>
</tr>
<tr>
<td>30</td>
<td>1.5</td>
<td>1.0</td>
<td>2.5</td>
</tr>
<tr>
<td>35</td>
<td>1.3</td>
<td>1.0</td>
<td>2.3</td>
</tr>
<tr>
<td>40</td>
<td>1.1</td>
<td>1.0</td>
<td>2.1</td>
</tr>
<tr>
<td>45</td>
<td>1.0</td>
<td>1.0</td>
<td>2.0</td>
</tr>
</tbody>
</table>

Table 2 – Inherent volume density gap reduction using a 65 ft. detection zone

For a 25-mph approach and a 0.5-second passage time, the minimum gap between vehicles that will cause a gap out is 2.3 seconds. However, at the beginning of the green while vehicles are just starting to go, the gap time is much higher (i.e. 4.9 seconds at 10 mph). As the vehicle speeds increase, the gap time reduces close to the ideal saturation flow rate, thus creating an inherent volume density gap reduction.

**Advantages of SmartSensor Matrix**

The detection design described in this application note is not possible or practical with many detection technologies, but the SmartSensor Matrix stop bar presence detector is uniquely suited to provide the detection required for this design. The advantages of the SmartSensor Matrix as a presence detector that make the long detection zone design possible are detailed below.
Vehicle-based Detection in a Large Coverage Area

The SmartSensor Matrix utilizes vehicle-based detection which means that vehicles are detected in the same way with the same level of performance regardless of the detection zone configuration. The sensor first detects a vehicle and then checks to see if the vehicle is inside a detection zone. This methodology is significant because it means the sensitivity of the detection zones is not dependent on the zone size.

Because SmartSensor Matrix is a non-intrusive sensor with a large coverage area, the creation of large detection zones is both possible and cost effective. The creation of a similarly large detection area with embedded sensors would be both difficult and costly.

Unaffected by Roadway Striping

The SmartSensor Matrix allows detection zones to be placed in the lanes of interest, in front of the stop bar, and over lane striping without negative consequences of false calls resulting from the visible reflectivity of the striping. By placing detection zones over the stop bar and in front of the stop bar, vehicles that creep forward past the stop bar will still be detected, thus eliminating the need for locking memory in the controller.

In the non-locking mode, an actuation received from a detector is not retained by the controller after the actuation is dropped by the detection unit. The controller recognizes the actuation only during the time that it is held present by the detection unit. This mode allows permissive movement (such as turning right on red) to be completed without invoking a phase change. In doing so, it improves efficiency by minimizing the cycle time needed to serve minor movement phases.

Since the sensor is unaffected by striping, the possibility of false detection due to striping does not increase when a long detection zone is created, again making the SmartSensor Matrix uniquely suited for the detection design described in this application note.

Tolerant to Environmental Conditions

Radar has the inherent characteristic of being tolerant to environmental conditions. Robust performance in the presence of rain, snow, fog, dust, wind and varying light conditions makes radar a solid technological choice for traffic detection.

Conclusion

The introduction of SmartSensor Matrix as a presence detector has made the use of long detection zones practical. A specific detection design utilizing long detection zones was presented in this application note and the advantages of this type of design were detailed. The characteristics of SmartSensor Matrix that make it uniquely qualified to provide presence detection with long detection zones were also described.

The Utah Department of Transportation contributed information for this application note.