A Gap-Based Approach to the Left Turn Signal Warrant

Jeremy R. Chapman, PhD, PE, PTOE
Senior Traffic Engineer
American Structurepoint, Inc.
March 5, 2019

Background

• The problem:
  - Existing signalized intersection
  - No left turn lane or protected phase
  - Multiple through lanes to cross
  - Currently seldom-used for left turns
    1) Drivers likely avoid turns due to delay
    2) Drivers take longer alternate route(s) to make right turn in instead
Background

This project:
- Focused on an alternate method to determine need for a protected left turn phase at an existing signal.
- Reviewed existing left turn warrants, and found them lacking for the specific location under study.
- Developed an alternate means to determine whether a protected left turn phase might be warranted for the study location.

Background

Different sources for warrants exist:
  1) MUTCD
  2) HCM
  3) FHWA
  4) ITE
  5) Individual states
  6) Other sources?
Background

Left turn warrants – commonalities

• All the left turn warrants examined for this project found basic commonalities:
  1) Volume-based
     - Requires volumes of both through and turning vehicles
  2) Delay-based
     - Requires delay values for turning vehicles
  3) Crash-based
     - Requires data for turning vehicle-involved crashes

Background

MUTCD:
  - No direct guidance for protected-permitted left turn warrants in the Federal MUTCD
  - Guidance does exist for installing a left turn lane
  - Is there anything else in the MUTCD signal warrants that can be used, however?
Background

HCM:
- HCM has a cross-product procedure where a left-turn phase be implemented when values shown are exceeded:

<table>
<thead>
<tr>
<th>Number of Opposing Lanes</th>
<th>Volume Cross Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>50,000</td>
</tr>
<tr>
<td>2</td>
<td>90,000</td>
</tr>
<tr>
<td>3</td>
<td>100,000</td>
</tr>
</tbody>
</table>

- Requires turning volume be known in addition to the through vehicle volume.
- No distinction for random vs. platoon arrivals.

Background

FHWA:
- *Signalized Intersections: Informational Guide* provides expanded guidance:

<table>
<thead>
<tr>
<th>Number of Opposing Lanes</th>
<th>Random Arrivals</th>
<th>Platoon Arrivals</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>45,000</td>
<td>50,000</td>
</tr>
<tr>
<td>2</td>
<td>90,000</td>
<td>100,000</td>
</tr>
<tr>
<td>3</td>
<td>Install Left-Turn Phasing</td>
<td></td>
</tr>
</tbody>
</table>
Background

ITE:

- *Manual of Traffic Signal Design (2E)* has 3 suggested guidelines for separate left-turn phases:
  - Volume: peak hour product >100,000 for 4 lanes, >50,000 for 2 lanes + 2 or more turning vehicles/cycle
  - Delay: left turn delay >2.0 vehicle-hours in peak hour
  - Crash History: 4+ in 1 year, 6+ in 2 years

Indiana:

- IDM: §46-10.04 (Left Turn from the Major Road)
  - Based on available intersection sight distance-based calculation of time gap (geometric, not operations)

  Design Vehicle  | Time Gap, t (sec)
  ---------------|-----------------
  Passenger Car   | 3.5
  Single-unit truck | 6.5
  Combination truck | 7.5

Divided Highway: For a left-turning vehicle entering more than one opposing lane, add 0.5 s for a passenger car, or 0.7 s for a truck, for each additional lane to be crossed and for a narrow median that cannot store the design vehicle.

Minor Road Approach Grade: If the approach grade is an upgrade that is steeper than 3%, add 0.1 s for each percent grade.

TIME GAP FOR LEFT TURN FROM THE MAJOR ROAD

Figure 46-10.1

- Does not account for available gaps/gap acceptance
Background

Left turn warrants – commonalities

• All the left turn warrants examined for this project found basic commonalities:
  1) Volume-based
  2) Delay-based
  3) Crash-based
• So what do you do if there are nearly zero turning vehicles currently?

Introduction

A recent project included evaluating a location with an existing signal (to accommodate exiting traffic) where:
  1) Occasional left turns in had been observed
  2) No left turn lane present
  3) No protected phasing present
  4) Three conflicting through lanes
Introduction

• Standard practice would be to use the left turn warrants

• Problem: NONE OF THEM APPLIED!!!!

Literature Review

Three source areas, covering research into:

1) Driver behavior during permissive phases
2) Critical gap/gap acceptance behaviors
3) Alternate warrants
Literature Review

Driver Behavior During Permissive Phases

- Many studies have looked into this
- Various factors considered:
  - Age/other driver characteristics
  - Driver distraction
  - Weather/environmental conditions
  - Trip purpose
  - Vehicle performance
  - Intersection layout
  - Pavement/road conditions
  - Traffic flow conditions

Literature Review

Driver Behavior During Permissive Phases

  - Basically comes down to available gaps and gap acceptance
Literature Review

Critical Gap/Gap Acceptance

• First, what is the “critical gap”?
  1) Not a direct measurement;
  2) Falls between a driver’s largest rejected gap and the smallest accepted gap;
  3) HCM (2000):

  *The critical gap is the minimum time interval between vehicles in a traffic stream that is acceptable for the driver to complete a conflicting maneuver.*

  4) Not a constant value, even for individual drivers.

• HCM base value for the critical gap for permitted left turns from a major street is 4.1 seconds.
  - Requires adjustments;
  - Single deterministic value, needs field verification


Literature Review

Critical Gap/Gap Acceptance
Not a constant value, why?
- Number of lanes to be crossed
- Speed of oncoming traffic
- Oncoming traffic density
- Presence/absence of left turn lane
- Drivers grow impatient and may ultimately accept a gap smaller than one they previously rejected.

Literature Review

Alternate Warrant approach
• Other MUTCD warrants:
  — Gap acceptance?

• Warrant 5: School Crossing
  - Uses a gap-based approach to determine if a signal is appropriate to allow pedestrians to cross without significant delay.
Project

- For the project study location, the following information was available:
  - Hourly through volumes
  - PHF
  - Lane widths

- As noted earlier, no left turn volumes were available.

<table>
<thead>
<tr>
<th>Time</th>
<th>Hourly Count</th>
<th>PHF</th>
</tr>
</thead>
<tbody>
<tr>
<td>00:00-01:00</td>
<td>235</td>
<td>0.955</td>
</tr>
<tr>
<td>01:00-02:00</td>
<td>198</td>
<td>0.955</td>
</tr>
<tr>
<td>02:00-03:00</td>
<td>84</td>
<td>0.955</td>
</tr>
<tr>
<td>03:00-04:00</td>
<td>98</td>
<td>0.955</td>
</tr>
<tr>
<td>04:00-05:00</td>
<td>113</td>
<td>0.955</td>
</tr>
<tr>
<td>05:00-06:00</td>
<td>179</td>
<td>0.955</td>
</tr>
<tr>
<td>06:00-07:00</td>
<td>54</td>
<td>0.955</td>
</tr>
<tr>
<td>07:00-08:00</td>
<td>1,180</td>
<td>0.955</td>
</tr>
<tr>
<td>08:00-09:00</td>
<td>1,193</td>
<td>0.955</td>
</tr>
<tr>
<td>09:00-10:00</td>
<td>943</td>
<td>0.955</td>
</tr>
<tr>
<td>10:00-11:00</td>
<td>796</td>
<td>0.955</td>
</tr>
<tr>
<td>11:00-12:00</td>
<td>803</td>
<td>0.955</td>
</tr>
<tr>
<td>12:00-13:00</td>
<td>803</td>
<td>0.955</td>
</tr>
<tr>
<td>13:00-14:00</td>
<td>803</td>
<td>0.955</td>
</tr>
<tr>
<td>14:00-15:00</td>
<td>803</td>
<td>0.955</td>
</tr>
<tr>
<td>15:00-16:00</td>
<td>803</td>
<td>0.955</td>
</tr>
<tr>
<td>16:00-17:00</td>
<td>803</td>
<td>0.955</td>
</tr>
<tr>
<td>17:00-18:00</td>
<td>803</td>
<td>0.955</td>
</tr>
<tr>
<td>18:00-19:00</td>
<td>803</td>
<td>0.955</td>
</tr>
<tr>
<td>19:00-20:00</td>
<td>943</td>
<td>0.955</td>
</tr>
<tr>
<td>20:00-21:00</td>
<td>1,103</td>
<td>0.955</td>
</tr>
<tr>
<td>21:00-22:00</td>
<td>1,150</td>
<td>0.955</td>
</tr>
<tr>
<td>22:00-23:00</td>
<td>1,150</td>
<td>0.955</td>
</tr>
<tr>
<td>23:00-00:00</td>
<td>1,103</td>
<td>0.955</td>
</tr>
<tr>
<td>Total</td>
<td>18,082</td>
<td></td>
</tr>
</tbody>
</table>

AM Peak  08:00-09:00  1,180
         09:00-10:00  1,193

PM Peak  17:00-18:00  1,150
         18:00-19:00  1,150
Project

Gap computation process:
1) Hourly volumes converted to peak 15 minutes using the corresponding PHF
2) The peak 15 minute volumes were then converted to average headways (in sec/veh).
3) Headways were then converted into flow rates (in veh/sec).

Project

Minimum gap length computation process:
1) The following data were used:
   - Average estimated turning vehicle speed = 10 mph
   - Average turning vehicle length = 20 ft
   - Traversable distance = 36 feet (three 12ft lanes)
   - Perception/reaction time = 3.0 seconds
2) Computed total travel distance
   - Sum of vehicle length and traversable distance = 56 feet
Project

Minimum gap length computation process:

3) Computed travel time using speed and distance
   = 3.9 seconds

4) Add perception/reaction time to get total travel time
   = minimum gap (sec) = 6.9 seconds

<table>
<thead>
<tr>
<th>Time of Day</th>
<th>Est. Avg. Turning Vehs. Speed (mph)</th>
<th>Vehicle Length (ft)</th>
<th>Traversable Distance (ft)</th>
<th>Total Travel Distance (ft)</th>
<th>Travel Time (sec)</th>
<th>Perception/Reaction Time (sec)</th>
<th>Total Travel Time = Minimum Gap (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AM</td>
<td>10</td>
<td>20</td>
<td>5</td>
<td>56</td>
<td>3.9</td>
<td>1</td>
<td>6.9</td>
</tr>
<tr>
<td>PM</td>
<td>10</td>
<td>20</td>
<td>5</td>
<td>56</td>
<td>3.9</td>
<td>1</td>
<td>6.9</td>
</tr>
</tbody>
</table>
Study Conclusions

- IDM warrant specifies that there be sufficient gaps for approximately 60 vehicles per hour to turn.

- During the AM peak hour, there are likely insufficient adequate gaps for left turning vehicles.

- If multiple vehicles arrived to make the left turn in a short time, the delay for left turns could be significant (6-10 minutes).
Conclusions

- Lots of variations for the left turn warrant exist.
- All require:
  - Turning and opposing volumes;
  - Left turn delay study; or
  - Left turn crash history.

- This methodology enables the computation of available gaps, and thereby the likely necessity of a protected left-turn phase, without knowing any of the information above other than the opposing volume.