Estimating Traffic Gaps for School Crossing Signal Warrants

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Abstract. One of the most challenging tasks for transportation professionals is providing accommodations for pedestrian street crossings, especially at school crossings. One typical solution is installing a signalized crossing. Prior to installation, the designer must first identify whether or not a traffic signal is needed – this is addressed by the Manual of Uniform Traffic Control Devices (MUTCD). The MUTCD establishes thresholds that must be met prior to installing a signal; for a signalized school crossing, the criteria are based on pedestrian volumes and gaps in traffic.

Determining the number of pedestrians crossing the street and calculating the amount of time pedestrians require to cross the street is relatively straightforward; however, identifying the number of gaps available in traffic is more involved. The best method, when time, money, and appropriate field conditions are available is to count the gaps and duration by direct observation. However, when the best method is not available, or if the transportation professional wants a preliminary estimate of gaps, a quality alternative should be sought. With this in mind, an empirical method was developed to estimate the number of gaps in the traffic stream based on readily available vehicular volume data. Such empirical methods, when backed with sufficient field data, provide the design professional with useful tools, ensuring sound school area pedestrian facility design.

Background

Installing a traffic signal for school area pedestrian crossings has been and continues to be a sensitive topic for traffic engineers and municipal agencies. When constituents become concerned about the safety of a pedestrian crossing, a citizen will make a request to local officials to signalize the pedestrian crossing. To support or refute the assertions, the local official conducts an engineering study. The engineering study must evaluate the warrants in the MUTCD to determine whether or not a signal is warranted. The MUTCD’s Warrant 5, School Crossing states that the warrant is satisfied if both of the following criteria are met:

- There are a minimum of 20 students crossing during the highest crossing hour; and
- The number of adequate gaps in the traffic stream during the period when the children are using the crossing is less than the number of minutes in the same period (1).

A typical school crossing engineering study for a warrant analysis relies on two different data elements: total number of pedestrians crossing and number of gaps of a certain length within a certain study time period. Both of these efforts are labor and cost-intensive.

The most convenient and cost-effective approach to gather the necessary data for the school crossing warrant is to have one technician collect the necessary data. Since the total number of pedestrians crossing cannot be estimated and must be counted, the single technician must concentrate on
collecting this data. If the technician concentrates on collecting pedestrian data, the second element, the number of gaps, requires an additional technician and an efficient data collection method.

When resources are limited to perform a complete analysis, it is often useful to have a screening tool to evaluate potential alternatives without the expense of collecting a large amount of data and spending time analyzing the data with an uncertain outcome. Such was the case in two communities where a municipality was trying to evaluate the feasibility and desirability of pedestrian traffic signals related to school crossings. To provide these municipalities with an initial assessment of whether or not the pedestrian crossings under evaluation would meet the School Crossing Warrant (1), a probability analysis was developed that used raw hourly traffic volumes at the crossing location as a method of determining if the evaluation should proceed to a complete analysis.

**Acceptable Gaps – Methodology**

The gap estimator relies on the principles of traffic flow theory, and the premise that vehicles are randomly distributed along a link. For this to occur, two conditions that must be met:

- Each vehicle is positioned by its driver independently of other vehicles; and
- The number of vehicles passing a point in a given length of time is independent of the number that passes that point in any other length of time (2).

The first condition typically occurs when traffic volumes are low so that vehicles do not bunch or are away from an intersection, so the side street volume does not influence flow on the mainline. The second condition typically occurs when the volumes are randomly distributed over the study time period and not consolidated into a smaller time period (e.g. when a factory shift ends or when a roadway is controlled by a signal). If both conditions are met, the gaps between two successive vehicles can be estimated using the Poisson distribution:

\[
P(h \geq t) = e^{-qt}
\]

Where \( P(h \geq t) \) is the probability that the headway is greater than or equal to a value defined;

- \( h \) = the headway;
- \( q \) = average traffic volume or ADT within a certain time interval (translated into vehicles per second for the time period in question);
- \( t \) = time interval used for the identified headway

Although this approach relies on headways, and the desired outcome is gap, the difference between the two is relatively small (e.g., assuming a 15 foot vehicle traveling at 25 mph, the difference between the headway and a gap is 0.18 seconds) and can be accounted for when identifying the acceptable gap (i.e., round up). Finally, the time interval, for the purposes of a gap study analysis, is equal to the necessary gap, or the time required for a pedestrian to cross the roadway:

\[
t = \frac{D}{V_c}
\]
Where $V_c$ is the crossing speed in feet per second; and

$D$ is the crossing distance (in feet.)

**Example – One-lane Street**

Considering a 20 foot wide street ($D = 20$ ft) with 500 vehicles per hour:

\[ q = \frac{500}{3600} = 0.139 \text{ vehicles per second} \]

Assuming that pedestrians walk at a rate of 4 feet per second:

\[ (V_c = 4 \text{ feet per second and } t = \frac{20}{5} = 4 \text{ seconds}) \]

Therefore, the probability that there is an acceptable gap is:

\[ P(h \geq 4) = e^{-0.139 	imes 4} = 50\% \]

The result can be interpreted as follows: the probability of any measured gap being equal to or greater than four (4) seconds, given the volume on the street, is 50% - note this is for one lane only. In summary, given the volumes on the street, and the time to cross, roughly half of all of the gaps will be acceptable for crossing.

**Two-Lane Roadways**

To further the analysis, it is necessary to consider the implications of using a probability estimate for crossing a two-way street. The first assumption is that the two traffic flows are independent of one another. If this assumption holds true, then multiplication nets the resulting probability of acceptable gaps on two-way streets. This rule comes from the rule of independence in probability (3):

\[ P(A \cap B) = P(A) \times P(B) \]

Where $P(A \cap B)$ is the probability of event A intersecting event B;

$P(A)$ is the probability of Event A occurring; and

$P(B)$ is the probability of Event B occurring.

In this case A could be representative of eastbound flow and B is representative of westbound flow.

If the probability of finding an acceptable gap in one direction is 50% and the probability of finding an acceptable gap in the other direction is 10%, the probability of finding an acceptable gap in both directions is 0.10 X 0.50 = 0.05.
Case Studies

This approach was used recently in two communities near Boston, MA where the decision makers were looking to determine whether a location warranted a pedestrian signal. Both locations are school crossings at unsignalized intersections, one in Newton, MA and the other in Brookline, MA.

In Newton, Massachusetts, the City was in the process of determining the optimal layout and site plan of a new high school. To ensure that a safe crossing would be designed, and to promote walking to school, the design team considered the possibility of a signalized pedestrian crossing at the main entrance to the site that would meet the goals of the project for pedestrian access. The probability analysis was a first step toward determining the feasibility of this approach in lieu of more extensive data collection efforts.

The Town of Brookline, Massachusetts was undertaking a similar analysis. The school crossing in Brookline was well established, but concerns had been raised about the safety of the crossing due to a school age pedestrian being struck at the intersection. The Town sought a recommendation on the most appropriate traffic control treatment for the crossing at the intersection. The probability analysis was a first step toward determining the feasibility of a pedestrian signal in lieu of more extensive data collection efforts, as was the case in Newton, MA.

Newton Application

The school crossing would be located at an unsignalized intersection approximately 900 feet from the nearest traffic signal. The proposed signalized school crossing is located on a 34 foot wide two-lane roadway near a high school. The land use in the area is primarily residential with nearby commercial. The available gap estimate was used here for a preliminary school crossing warrant.

To estimate the number of gaps with the gap estimator, it is necessary to first determine if the independence requirements are met. The first requirement is met if the flow is not in a congested condition, which, given the volumes, there is ample roadway capacity to handle the moderate volumes (approximately 1350 vehicles per hour (morning peak - both directions combined). The second requirement is met if the distribution of vehicles is random over the length of the study period.

The first requirement was fulfilled – considering the capacity of a two-lane roadway, the recorded volumes were at a level where drivers’ were not influenced by other vehicles in the traffic stream. The second requirement was not easily achieved - the flow is interrupted by traffic signals. The signals could uncharacteristically bunch vehicles and change the random arrival patterns. However, in this case, since the signal is approximately 900 feet away, it was assumed that the influences of the signal had little effect at this point.

Considering this, a preliminary assessment was performed, realizing that the signals may influence traffic stream characteristics. The estimated street crossing time in Newton, is nine seconds, therefore, the acceptable gap is nine seconds. Using the methodology described above, there were 47 total gaps equal to or larger than 9 seconds (Table 1) during the morning peak hour.
Table 1  Available Gaps (> 9 Seconds) - Morning Peak Hour, Newton, MA

<table>
<thead>
<tr>
<th></th>
<th>Volume (vph)</th>
<th>Available gaps (%) (e⁻⁹)</th>
<th>Number of Gaps</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eastbound</td>
<td>714</td>
<td>17%</td>
<td></td>
</tr>
<tr>
<td>Westbound</td>
<td>634</td>
<td>20%</td>
<td></td>
</tr>
<tr>
<td>Total (both directions)</td>
<td>1,348</td>
<td>3.4%</td>
<td>46</td>
</tr>
</tbody>
</table>

Additional gap data were collected to validate the model. The data collected indicated that there were 56 acceptable gaps, or ten more than what was predicted. This is a point comparison of the estimate to the actual data, but it is also important to understand whether the assumed Poisson distribution matches that actual distribution of traffic measured in the field.

As a second check, the field collected data were compared to the estimates (Figure 1). Based on the graphed data, the assumed distribution is very close to the actual field counts measured for the school crossing in Newton, which implies that this is a reasonable estimator. The point estimate was close but not exact, which is to be expected when working with probability distributions.

Figure 1  Available Gaps Comparison - Field to Estimated - Morning Peak Hour, Newton
Both the estimated total number of acceptable gaps and the measured number of acceptable gaps meet the requirements for a school crossing warrant since the total number was less than the minutes in the study period (60 in this case). Therefore the signal was warranted.

**Brookline Application**

The school crossing would be located at an unsignalized intersection which operates much like a signalized intersection when the school children are crossing because there is a crossing guard on duty. The intersection is located approximately 550 feet from the nearest signalized intersection. The proposed signalized school crossing is located on a 26 foot wide two-lane roadway near an elementary school, and the surrounding land use is residential. The available gap estimate was used here for a preliminary school crossing warrant.

Prior to using the gap estimator, it is necessary to determine if the randomness requirements are met. The first requirement, free-flowing condition - based on field observations, this requirement is met. The second requirement, random distribution, was not met – a crossing guard on duty during the study time period that creates artificial gaps, much like a traffic signal.

Since the time the guard was on duty coincided with the time when school children crossed the street, an alternate approach was used. Data were collected farther upstream, away from the influences of the crossing guard. This illustrates the usefulness of the estimate for cases where on-site constraints pose challenges, or where a preliminary estimate is sought.

An acceptable gap of 11.43 seconds was calculated using the curb to curb distance crossing Walnut Street on the east side of the intersection (40 feet) and a crossing distance of 3.5 feet per second. A slower walking speed was used at this location due to the large amount of elementary school children crossing the intersection, unlike the high school students in Newton. The volume in the morning peak hour (7:00 – 8:00 a.m.) was relatively small – in the eastbound direction, there were 418 vehicles per hour (vph) and in the westbound direction, where were 149 vph, or a combined volume of 567 vph.

Using the estimator, with the volumes, and acceptable gap it was determined that in the morning peak hour there were 94 acceptable gaps in two-way traffic. This value was calculated from each one-way probability (Table 2).

<table>
<thead>
<tr>
<th>Volume (vph)</th>
<th>Available gaps (%) (e^-q)</th>
<th>Number of Gaps</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eastbound</td>
<td>418</td>
<td>27%</td>
</tr>
<tr>
<td>Westbound</td>
<td>149</td>
<td>62%</td>
</tr>
<tr>
<td>Total (both directions)</td>
<td>567</td>
<td>17%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>97</td>
</tr>
</tbody>
</table>
Using the methodology outlined above, the probability of having an acceptable gap of equal or greater than 11.43 seconds in the eastbound direction is 27% and in the westbound direction, 62%; therefore, the probability of finding a gap in both directions is 17 percent (0.62 X 0.27). Using the sum of vehicles as an estimate for total number of two-way gaps, the formulation estimates that there are 97 acceptable gaps on Walnut Street in Brookline in the morning peak hour. Additional data was collected upstream of the location of the school crossing to validate the model. The data show that there were approximately 77 gaps of 12 seconds or longer, 20 less than predicted.

As was the case with the Newton case study, graphing the distributions gives a better understanding as to the applicability of the estimator (Figure 2). The assumed distribution is very close to the actual field counts measured for the school crossing in Newton, which implies that the estimate is valid.

![Figure 2 Available Gaps Comparison - Field to Estimated - Morning Peak Hour, Brookline](image)

Given that the School Crossing Warrant requires that there be less gaps than minutes in the time period (60 minutes in this case), the warrant is not met.

**Conclusions**
The probability analysis methodology relies on meeting specific requirements for statistical independence and distribution. If those requirements are met, then this method of estimating the acceptable number of available gaps for pedestrian crossings is applicable and useful as a screening tool for preliminary analysis or as a means for generating estimates when field conditions preclude actual gap counts. The method allows for professionals to collect straightforward ADT volumes and arrive at a faithful estimate of what field conditions would look like if there were no data collection restrictions. It is important to note that the estimates should be used with caution, especially when the statistical conditions are not met or are in question.

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References


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