An Empirical Bayesian Evaluation of the Safety Effects of High-Visibility School (Yellow) Crosswalks in San Francisco

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ABSTRACT

The Empirical Bayesian (EB) Method, currently the industry standard for before-and-after collision analysis, was used to perform tests on the efficacy of high-visibility school (yellow, continental-style) crosswalks in the City of San Francisco. Statistical analysis compared the number of collisions predicted for the after period had the enhanced crosswalks not been installed to the number of collisions observed. The analysis used data for 54 treated intersections with high-visibility crosswalks and 54 control intersections, each chosen for their geographical proximity to a treated intersection. Results from this analysis suggest a statistically significant reduction in collisions at the intersections with high-visibility crosswalks. The estimated reduction is 37 percent, with a 95% confidence interval ranging from 13 percent to 60 percent. Potential limitations of this analysis, including a constant traffic volume input over time and a background reduction in collisions citywide, are discussed.

In addition to the safety benefit attributable to high-visibility crosswalk markings, high-visibility crosswalks likely contribute to a sense of pedestrian comfort and overall design amenity. Future studies would enhance these results by evaluating other factors that may affect pedestrian safety at school crosswalks, such as changes in driver and/or pedestrian behavior and increased awareness of crosswalks and pedestrian activity.

INTRODUCTION

This paper summarizes a statistical analysis of the crash reduction efficacy of high-visibility (yellow, continental-style) school crosswalks in San Francisco using the Empirical Bayesian (EB) method. The following sections present the background for this study, a review of related research on crosswalk markings, and a review of the statistical analysis methods for evaluating treatment efficacy. The data sets are then discussed followed by the selected statistical analysis method and results. The paper concludes with a discussion of next steps and future research needs.

BACKGROUND AND MOTIVATION

Walking is a critical piece of San Francisco’s transportation system. Even with its famous steep and crooked streets, San Francisco’s climate, grid network, and transit system combine to make it one of California’s most walkable cities. Walking trips make up 20 percent of all trips in San Francisco. Of the 700,000 daily boardings on Muni (San Francisco’s public transit system), the vast majority start or end with a walking trip. Recognizing the role of walking, San Francisco is continually trying to improve the pedestrian environment in general – and pedestrian safety specifically.
Historically San Francisco’s high number of pedestrians has coincided with a high number of vehicle-pedestrian collisions. In 1998 there were 4,599 non-fatal injury collisions and 53 fatal collisions in San Francisco – of those, 985 (21 percent) non-fatal collisions involved pedestrians and 32 (60 percent) fatal collisions involved pedestrians. In 2006, the most recent year of complete data, there were 726 (24%) non-fatal vehicle-pedestrian collisions and 13 (46%) fatal vehicle-pedestrian collisions (1). The number of pedestrian-involved collisions has been decreasing over time, but pedestrians continue to be overrepresented in injury and fatal collisions relative to their exposure. Although the downward trends in collisions are encouraging, one pedestrian death is simply too many.

Nationally children and senior citizens are overrepresented in vehicle-pedestrian collisions and in their resulting injuries. Children are typically overrepresented because they lack the cognitive skills to accurately judge vehicle speeds and to identify safe gaps in traffic, they are physically smaller and harder for drivers to see, and they may dart into the street, not giving drivers sufficient time to react to their presence. When developing its crosswalk policies, San Francisco decided to focus its use of high-visibility crosswalks in school areas, where it had the potential to benefit this vulnerable population. In some San Francisco neighborhoods, these crosswalks also disproportionately benefit seniors. Particularly in its ethnic communities, many San Francisco grandparents are their grandchildren’s primary caregivers during the day. Consequently, school crosswalks are heavily used by students and seniors who take them to and from school. This is among the reasons why San Francisco made a commitment to install high-visibility crosswalks at all marked school crossings in the city.

Starting in 2000, the San Francisco Municipal Transportation Agency (SFMTA) converted all standard, yellow school crosswalks at some 900 locations to high-visibility, yellow, continental-style striping. These upgrades were completed either as part of a local sales tax funded project or as part of planned repaving projects. Over one million dollars was spent to upgrade school crosswalks and to replace yellow school warning signs with florescent yellow-green warning signs throughout the city. The impetus in making these changes was to increase driver awareness of the schools and hopefully to improve student safety.

Understanding the pedestrian safety benefit of high visibility crosswalks is important to San Francisco because the SFMTA has been under increasing pressure to use high-visibility crosswalks at more non-school locations. San Francisco’s current policy is to use high-visibility crosswalks at school crossings and at uncontrolled, midblock crossings – locations believed to benefit from additional warning of pedestrian activity. However, continental-style crosswalks are four times more expensive ($1700 per crosswalk) to install and maintain in San Francisco than standard crosswalks.

Documenting a safety benefit could justify a change to existing crosswalk policies to expand the use of high-visibility crosswalks with the potential to benefit other vulnerable pedestrian groups and the general public. Conversely, if there is not a safety benefit, there is less justification to expand the use of high-visibility crosswalks, at least while available funding is constrained.
Added motivation to complete this study is San Francisco’s ongoing process to adopt its “Better Streets Plan” – a document that will lay out a vision for public pedestrian space and that will establish detailed design guidelines. Research on crosswalk design will help inform the city’s community discussions and policy recommendations at this influential time.

RELATED STUDIES

Several previous studies have evaluated statistical methods for measuring the collision reduction efficacy of crosswalk treatments. Studies have also considered other safety measures for evaluating crosswalk treatments, such as yielding behavior.

Studies of Crosswalk Marking Styles

A 1998 study by Várhelyi on driver behavior at zebra- (continental-) style marked crosswalks in Sweden indicated that drivers only yielded to pedestrians 5 percent of the time, concluding that driver behavior needs to be influenced approximately 40 to 50 meters before the zebra crossing in order to increase the yield rate (2).

Zegeer, et al. (2001) conducted a nationwide study of pedestrian-vehicle collisions at marked versus unmarked crosswalks at uncontrolled locations. The study concluded that there is no significant difference in pedestrian safety at marked versus unmarked crosswalks on lower volume, two- and three-lane roads (3). This finding changes, however, with an increase in average daily traffic volumes, number of lanes in the roadway, and more pedestrian traffic. Marked crosswalks at uncontrolled multi-lane roadway intersections were found to have a significantly higher pedestrian collision rate. Furthermore, the use of a median on multi-lane roads lowered the pedestrian collision rate. Although crosswalk striping pattern was included as a variable in the regression analysis for the number of collisions at each study location, the marking style was not found to be statistically significant.

In a review of existing literature on visibility aids and bicycle and pedestrian safety, Kwan and Mapstone (2002) found that countermeasures using florescent yellow, orange, and red colors effectively increase visibility of pedestrians during daylight (4). Turner’s (2006) study of motorists’ yielding habits at unsignalized intersections with various traffic-calming measures found that treatments with a red indicator were a statistically significant factor in encouraging motorists to yield to pedestrians (5). However, the efficacy of high-visibility signs and markings were mixed. The high-visibility signs and markings had the second lowest average yield rates of the nine treatments studied and did not have a statistically significant different yield rate than other treatments studied. The high-visibility markings had higher yield rates on lower-speed roadways. Turner also noted the importance of education in influencing driver and pedestrian behavior.

Several recent studies have discussed the role of colored pavement markers in influencing driving behavior. Though not specific to crosswalks, Parham’s (2003) study of driver understanding of pavement colors and patterns found that drivers understood the difference in meaning between yellow versus white pavement markers, to a greater extent than hypothesized (6). Parham also found that the yellow versus white color distinction was not the primary factor
in drivers’ understanding of the rules of road; instead, signage and the behavior of surrounding traffic served as the primary factor in drivers’ understanding of roadway rules. However, a study by Schnell (2007) indicated that yellow pavement markings are not always effective, because they are often not perceived as yellow (7). At night, newer yellow pavement markers that lack lead in the paint often appear white. The color of a vehicle’s headlights can also contribute to yellow markers appearing white.

No previous studies of the collision-reduction efficacy of yellow school crosswalks were identified in the literature review for this study.

**Statistical Analysis**

Current literature promotes the Empirical Bayesian (EB) method as a new industry standard for before-and-after collision analysis. Many studies falter in accurately estimating how many collisions would have occurred if a given improvement had not been in place. The EB method allows researchers to estimate collision rates without the improvement based on collision counts from before the improvement was made and counts from a control group of untreated locations that are carefully matched with the study sites. The EB method assumes that the number of collisions fits either the Poisson or the Negative Binomial distribution.

Powers and Carson (2004) examined the increased accuracy in estimating the effects of the safety improvements for before-and-after studies using the EB method (8). They noted that the EB method treats the regression-to-mean bias, which creates artificially high estimates of an improvement’s benefit because study sites are often chosen based on their abnormally high number of collisions. Those numbers, because of the random nature of collisions, would have decreased naturally over time, regardless of whether or not the study sites were treated. The Powers and Carson study is in line with Howard et al. (2001), who reported that the EB method should be the preferred practice to analyze safety before and after a treatment (9).

Fitzpatrick and Park (2009) examined the effectiveness of HAWK (High Intensity Activated Crosswalk) pedestrian crossing beacons in reducing different types of crashes at a set of intersections in Tucson, AZ (10). They assumed the number of crashes fit a negative binomial distribution, and used the EB method to successfully show that the HAWK beacons were effective at reducing pedestrian crashes and crashes in aggregate.

**DATA SETS**

San Francisco was uniquely situated to be the subject of this study because of its size and the amount of data available to complete the analysis. With over 800 school crosswalks in the city, it was safe to assume that there would be enough study locations to generate statistically significant results. When the standard school crosswalks were upgraded to high-visibility crosswalks, a database was used to track their location and the date of the installation. SFMTA also maintains databases that identify the location of schools, adult crossing guards, traffic signals, and stop signs. Finally, SFMTA uses collision analysis software that can generate a database of geocoded collisions for spatial analysis.
The source of data for this study was SFMTA’s GIS databases. The analysis database contained one record for each pedestrian-vehicle intersection collision in San Francisco from 1994 to 2006. To test the efficacy of high-visibility (treated) crosswalks, the collisions and crosswalk installation information, along with other intersection characteristics, were compiled into one record for each intersection, and the number of collisions before and after the installation of the high-visibility crosswalk was computed for each intersection. The aim of the tests was to determine whether the treatment was effective in reducing the number of collisions at the treated intersections.

Data Characteristics

The treated group was chosen from the GIS database provided by SFMTA. The initial set of intersections with high-visibility crosswalks contained 861 records. However, many of the intersections did not have a value for average daily traffic (ADT) in the city’s GIS database, and ADT was a prime candidate to be a predictive characteristic for the SPF component of the EB method. In addition, the treated group was reduced to intersections that had at least three years of observations both before and after treatment to maximize the analysis timeframe. Since the collision data covered the years 1994-2006, treatment had to occur between January 1, 1997 and December 31, 2003 in order for the intersection to be included. This reduced the data to 99 intersections.

Finally, to ensure that similar intersections in each group were being analyzed with respect to their pedestrian counts (which were not available), an intersection in geographical proximity to each of the 99 intersections left in the treated group with a similar value for ADT was selected as a control site. If possible, intersections with a common major street were selected as matches. At the end of the process, 54 of the 99 eligible treated intersections had “matching” intersections in the control group. The EB method does not require that the treated and control groups be the same size; however, this process was the best way to ensure that the analysis controlled for pedestrian counts, and other immeasurable factors such as school proximity, perceived neighborhood safety, and sidewalk quality.

STATISTICAL ANALYSIS

Empirical Bayesian (EB) Method

The Empirical Bayesian (EB) method is an alternate test of efficacy, designed to predict future performance of a treated intersection by weighting its past performance with an estimate based on data for similar intersections. More details on the EB method are available elsewhere (8, 9), but the general procedure is outlined here.

Step 1: Safety Performance Function

The EB method requires the determination of a Safety Performance Function (SPF) by statistical analysis. The SPF is a multivariate regression formula that fits collision data for control intersections to a set of independent variables that can be expected to affect safety, such as ADT, street width, or signal type.
Due to the non-normality of collision data, the preferred model for the SPF is a log-linear model, estimated by maximum likelihood and assuming either a Poisson or a Negative Binomial distribution for the collision data. The choice of distribution is governed by an overdispersion test, which compares the likelihoods of the two possible models, and chooses the Negative Binomial Model if a Chi-Squared test determines that it is significantly “likelier.” Data that exhibits more variability tends to favor the Negative Binomial distribution, and that was the result in the tests for this study.

The SPF was generated on the set of 54 control intersections. The resultant SPF was:

\[
\ln(\text{# of Collisions in 13 years}) = -8.637 + 0.906 \times \ln\text{ADT} + 0.027 \times \text{Major Street Width (feet)} + 0.994 \times \text{Signalized} - 2.056 \times \text{Uncontrolled} - 0.96 \times \text{Non-local}
\]

Where \(\ln\text{ADT}\) is the natural log of daily traffic volume count (as provide by SFMTA), “Signalized” is equal to 1 if the intersection is signalized, 0 otherwise, “Uncontrolled” is equal to 1 if the intersection is neither signalized or stop-controlled, 0 otherwise, and “Non-local” is equal to 1 if the SFMTA street classification is not “local” on at least one street in the intersection.

The Scaled Deviance and Pearson Chi-squared Statistics are generally used to measure model goodness of fit in negative binomial regression, with values close to 1 representing the best fit. The SPF above achieved a Scaled Deviance of 1.026 and a Pearson Chi-Squared Statistic of 0.978. The negative binomial dispersion parameter, used in subsequent steps of the analysis, was estimated to be 0.776.

**Step 2: Estimation of Before-Period Collisions for Treated Intersections**

The characteristics of each treated intersection are inserted into the above SPF, and a ratio of (Length of before-period) / (13 years) is applied to each intersection to normalize the estimate for the length of time. The before-period lengths vary for each intersection depending on when the high-visibility crosswalk was installed. This results in \(\text{SPFi}\), the expected number of collisions at intersection \(i\) in the before-period based on the SPF.

**Step 3: Estimation of After-Period Collisions for Treated Intersections**

To produce an estimate of collisions for each treated intersection *had it not been treated*, \(\text{Mi}\), a weighted average is taken between the SPF estimate and actual before-period observed data as follows:

\[
\text{Mi} = \text{Wi} \times \text{SPFi} + (1 - \text{Wi}) \times \text{Ki}
\]

where \(\text{Ki}\) is the observed collisions in the before-period at intersection \(i\), and \(\text{Wi}\), the weight for intersection \(i\) is:

\[
\text{Wi} = \frac{1}{1 + k \times \text{SPFi}}
\]

where \(k\) is the negative binomial overdispersion parameter. This parameter is higher when there is more variability in the observed data. Thus, more weight is attached to the SPF, and less to the observed data, if there is less variability for the observed data.
Since $Mi$ is an estimate based on the length of the before-period, the estimate has to be normalized to the length of the after-period. Thus, $\pi_i$, the estimation of after-period collisions at intersection $i$, is

$$\pi_i = M_i \times C_i$$

where $C_i$ is the ratio of the length of the after-period to the length of the before-period at intersection $i$.

**Step 4: Estimate the Index of Effectiveness**

The index of effectiveness $\Theta$ is a measure of how effective the treatments are, based on comparing the estimations in step 3 with the actual number of collisions after the treatment, i.e. after the high-visibility crosswalks were installed. The formula for the estimate for $\Theta$ is

$$\theta = \frac{L}{\pi \times (1 + \text{var}(\pi) / \pi^2)}$$

where $L$ is the total number of collisions in the after-periods of all intersections in the treated group, and $\pi$ and $\text{var}(\pi)$ are computed as follows:

$$\pi = \sum_i \pi_i \quad \text{var}(\pi) = \sum_i C_i^2 (1 - W_i) M_i$$

If $\Theta$ has a value of less than one, then the treatment is estimated to have a positive effect on safety. The percent change in collisions is $100 \times (1 - \Theta)$. A 95 percent confidence interval for $\Theta$ can be estimated by computing the standard error of $\Theta$, $se(\Theta)$, with the following formulae:

$$\text{var}(\theta) = \theta^2 \frac{1/L + \text{var}(\pi) / \pi^2}{(1 + \text{var}(\pi) / \pi^2)^2} \quad se(\theta) = \sqrt{\text{var}(\theta)}$$

The 95 percent confidence interval is then obtained by adding and subtracting $1.96 \times se(\Theta)$ from $\Theta$. If $\Theta < 1$ and the confidence interval does not contain 1, then the EB method suggests there has been a statistically significant safety benefit to the treatment.

**Results**

Table 1 presents the results of the various steps outlined above, presented both in total number of collisions (for the 54 treated intersections) and on a collisions per intersection per year basis. Note that the before and after periods are not the same for each intersection; the crosswalks were installed between 2000 and 2003.

The final two lines of Table 1 show that the actual number of collisions for the treated intersections was significantly lower than estimated. The index of effectiveness $\Theta$ was 0.63 (calculated with the formula in step 4 above), with a standard error of 0.12. This resulted in a 95 percent confidence interval of (0.40, 0.87). Thus, the EB method estimated that there has been a
37 percent improvement to safety at the treated intersections, with a 95 percent confidence range of 13 to 60 percent.

<table>
<thead>
<tr>
<th>COLLISION QUANTITY</th>
<th># OF COLLISIONS</th>
<th>AVERAGE PERIOD LENGTH (YEARS)</th>
<th>COLLISIONS PER INTERSECTION PER YEAR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual Before Period (ΣKi)</td>
<td>99</td>
<td>7.8</td>
<td>0.23</td>
</tr>
<tr>
<td>SPF – Before Period (ΣSPFi)</td>
<td>74</td>
<td>7.8</td>
<td>0.17</td>
</tr>
<tr>
<td>Estimated – Before Period (ΣMi)</td>
<td>88</td>
<td>7.8</td>
<td>0.21</td>
</tr>
<tr>
<td>Estimated – After Period (Σπi)</td>
<td>53</td>
<td>5.2</td>
<td>0.19</td>
</tr>
<tr>
<td>Actual – After Period (L)</td>
<td>34</td>
<td>5.2</td>
<td>0.12</td>
</tr>
</tbody>
</table>

CONCLUSION

The analysis results suggest a statistically significant reduction in collisions with the installation of high-visibility school crosswalks. This finding supports the city’s significant investment in this safety countermeasure.

Several potential limitations to this study should be noted. First, the study did not consider many of the other factors that may contribute to improved pedestrian safety, such as changes in driver and/or pedestrian behavior and increased awareness of crosswalks and pedestrian activity. Collision data was the other measure of safety considered. Second, pedestrian-vehicle collisions are rare and notoriously underreported. As such, future studies of “near misses” and collision underreporting could enhance this study and provide a more complete evaluation of school crosswalk treatments.

Finally, the analysis method did not explicitly address the general downward trend in pedestrian-related collisions throughout San Francisco during the time observed. However, the EB method does take background trends into account, as the SPF is estimated with collision data for the control group from this entire period. Additionally, both the control and treated group experienced the background trend.

NEXT STEPS

As mentioned previously, San Francisco is in the process of creating its “Better Streets Plan.” To date, the planning and outreach process has generated hundreds of suggestions for
improving San Francisco’s public realm – most of which have no dedicated funding source. The results of this study will be shared with the public and San Francisco city departments to inform decisions about how to allocate scarce resources for improving the pedestrian environment.

Future research needs include identifying and quantifying any outside trends that have led to a reduced number of overall pedestrian collisions in San Francisco. This research would make it easier to isolate the effect of high-visibility crosswalks from any residual background trend not captured in the EB method.

Additionally, to the extent that the high-visibility crosswalks contribute to a sense of pedestrian comfort and overall design amenity as well as enhanced safety, their cost/benefit may improve. This benefit could be quantified with future research.

Finally, groups of safety countermeasures, such as crosswalk markings, along with school crossing guards, countdown pedestrian signals, and other safety enhancements, should be evaluated for their potential to further enhance safety at school crossings and, in doing so, encourage more children to walk to school.

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