Safety Assessment of Installing Traffic Signals at High-Speed Expressway Intersections

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ABSTRACT

This paper reports the status and preliminary results of an ongoing study investigating the safety benefit of signalizing intersections of high-speed (50 mph and greater) divided expressways. Before and after analysis was conducted and compared to empirical Bayesian (EB) techniques. A safety performance function was developed using negative binomial regression for a control group of 67 non-signalized intersections and compared to the performance of 20 intersections signalized between 1994 and 2001. Cross-sectional analysis was performed on 67 signalized and 67 non-signalized locations using negative binomial regression analysis to control for traffic volume. The paper reports on the effect of signalization on crash frequency and compares the results of the EB method with traditional statistical techniques.

Keywords: empirical Bayes—expressway intersections—traffic signals
BACKGROUND

This paper reports on an ongoing study of the safety effectiveness of installing traffic signals on high-speed expressways. A high-speed expressway is defined as a roadway with at-grade intersections with at least two lanes of traffic traveling in each direction that are separated by a median, with a speed limit of 50 mph or greater. The study sought to determine the safety effectiveness of installing traffic signals along the expressways. The study also evaluated empirical Bayes (EB) as an alternative statistical approach (e.g., effort vs. benefit).

At-grade expressway intersections are the location of many serious crashes and are typically controlled by a stop sign or a traffic signal. At stop-controlled intersections, as traffic levels increase, cross-street drivers may be forced to accept increasingly shorter and fewer gaps. At light traffic levels, mainline drivers may experience unnecessary delay if signal-controlled. Adding signals may not increase safety, as many would expect; rather, the types and severities of crashes may shift. If signalized, turn lanes may be used to separate some movements to reduce some rear-end crashes. Intersection skew is also a factor, particularly at angles of less than 75°. Research is underway (e.g., National Cooperative Highway Research Program [NCHRP]) to examine geometric improvements that might be used to increase traffic flow and enhance safety in lieu of signalization or grade separation.

This study used traditional statistical methods to examine the safety effectiveness of signalization and compares the results with those computed using the EB statistical method, widely noted as the state of the art in crash analysis, as it reduces the effect of small data samples (resulting in regression to the mean) and provides better estimates than older methods. Traditional methods include cross-classification and before and after analysis using pooled data sets. Cross-classification was used to compare the safety performance of non-signalized intersections (including intersections prior to signalization) to that of the signalized intersections (including intersections after signalization), accounting for covariates using regression techniques.

RESEARCH OBJECTIVES

As mentioned, signalizing a high-speed expressway intersection is likely to change crash type, but does not necessarily reduce crash rate or severity. To provide a baseline for comparison, the first objective of the study was to assess the safety impact of signalization at high-speed expressway intersections using traditional statistical methods.

The second objective was to compare the results (and input requirements) using EB analysis to the traditional methods. As Bayesian methods are new to many practitioners and have yet to find widespread implementation, the comparison should be useful to analysts considering various statistical approaches.

RESEARCH APPROACH

For the present study, an initial set of intersections was selected from a previous study of signal phasing to perform a preliminary analysis. The first task was to identify the expressway intersections in Iowa, a rather nontrivial exercise, as centralized data for road characteristics are maintained by the Iowa DOT while information on signals is maintained by local agencies that own and maintain them. This database contained information on the number of lanes, access control, median type, speed limit, and control...
devices on road segments. The first step in identifying additional candidate intersections was to select all expressway and intersecting roads in the state. Next, segments were examined for indications of traffic signals. These segments were spatially compared to a separate database of known intersection locations (nodes). If any node was found to be within 200 ft of any signalized high-speed expressway segment, the node was labeled and stored as a high-speed intersection location. The method also designated some nodes erroneously (see Figure 1). These extra intersections were manually removed from the database. From remaining candidate intersections, aerial imagery was examined to verify the presence of a traffic signal.

![Figure 1. Intersection identification problem](image)

While examining the aerial photographs, data were collected for each intersection. Figure 2 displays high-resolution aerial photography of the intersection of IA 28 and Park Avenue in Des Moines. Imagery used for the project ranged from six-inch to one-meter resolution. From the imagery, number and length of turn lanes, median type and width, and skew angle can be measured. More information about the intersections (traffic volume and date of expressway construction) was obtained from the Iowa DOT road network database.

![Figure 2. Aerial image of IA 28 and Park Ave](image)

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1 The database was not completely consistent with regard to identifying presence of signal, and did not include signal installation or modification date and hence was not capable of identifying all of the intersections of interest in the state.
In the absence of a statewide intersection control database, date of installation had to be approximated. To do this, crash records were examined for each intersection, and presence or absence of signal control was noted. Figure 3 illustrates the method used to approximate date of installation. Date of installation was identified to coincide with consistent reporting of signal presence in the crash database. In the example, note that prior to 1996 most crash reports indicated no signalization. Similarly, after 1996 stop control was reported infrequently. It is unclear why all crash records are inconsistent with regard to traffic signal presence. Therefore, judgment was used to approximate dates of installation. The final list of installation dates was shared with state DOT personnel and, in one case, follow up communication was initiated with local officials to confirm the installation date.

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1 - No Controls Present in Crash Record
2 - Traffic Signals
3 - Stop Signs

Should be at least 3 years between Traffic Signal Installation and either a modification or begin/end of the available data.

**Figure 3. Example of estimating the date of traffic signal installation**

To create a comparison group of non-signalized intersections, intersections were selected where minor road volumes fell within the range of minor road volumes on the signalized dataset. Aerial images at each of the intersections were examined for turn lanes, median, speed limit, skew angle, and traffic volume, trying to match as closely as possible the signalized intersections to facilitate pair-wise comparison. To verify that the comparison group consisted of only non-signalized intersections, aerial imagery was examined. In a few instances (see Figure 4), there was evidence of signalization. In these cases, alternate imagery was obtained and examined. For example in Figure 4, there is a faint indication that a signal may be at the intersection. From Figure 5, signals can be clearly identified.

**Figure 4. Aerial image signalized expressway intersection**

**Figure 5. Higher resolution image**
After the study intersections were identified, crashes were selected for each. Crashes were initially spatially selected (within 150 feet, the distance commonly used by the Iowa DOT in their rural analyses). However, spatial proximity does not always indicate relevance of crash to intersection. Figure 6 illustrates this. Each circle shows the approximate number of crashes at an intersection. The blue circle indicates the number of crashes that meet the attribute representation of “intersection-related.” The yellow circle shows the number of crashes that are within the spatial proximity. The red circle shows the number of crashes that meet both (attribute and spatial). Each classification gives a significantly different number of total crashes at the intersection. Several items from the crash data were also used to indicate “intersection-related” crashes. Values for some items are indicative of intersection proximity (at or near intersections, group one), while others indicate the type of crashes that generally occur or do not occur at intersections (i.e., right-angle, rear-end, parked vehicles, and driveway related crashes, group two).

Figure 6. Intersection crashes

Figure 7 shows how the number of intersection related crashes would vary based on selection criteria over the time of interest of this study. Methods illustrated include the following:

- Crashes within 500 ft of the intersections (500)
- Crashes where one group of properties indicate intersection-related crashes and within 500 ft (possible at 500)
- Crashes where both groups of properties indicate intersection-related crashes and within 500 ft (likely at 500)
- Crashes within 150 ft of the intersection (150)
- Crashes where one group of properties indicate intersection-related crashes and within 150 ft (possible at 150), used for the present analysis
- Crashes where both groups of properties indicate intersection-related crashes and within 150 ft (likely at 150)
It should be noted that crashes prior to 2000 were located based on a distance from a node (typically an intersection). After 2000, crashes were located spatially along the highway segment. Nodes (prior to 2000) and cartography (after 2000) were updated periodically, resulting in some discrepancies between crashes located on older versions to more recent crashes, and more importantly to underlying road cartography and attributes. To account for these spatial inaccuracies, intersection locations were located using both 1998 and the 2003 alignments. Another issue with creating a second set of intersections is illustrated in Figure 8. If a second intersection location is offset from the expressway and/or from the side road, crashes should be selected that are outside the 150 ft tolerance. (Intersection-related criteria may have eliminated these crashes, but has not been checked at this time.) Within the study timeframe, the minimum crash reporting threshold also changed. Furthermore, the crash reporting form itself changed in 2001. In the changeover, approximately 5,000 crashes were reported on the old form and have not been changed to the new form (and consequently are not in the database). During this period, the crash database architecture also changed. To account for the report form change, a second list of crash properties were created and separated into two groups that are similar to the previous groups.
Once all the data were collected, analysis began by analyzing only the intersections that had at least three years of crash data before and after the traffic signal was installed. This limited the number of intersections to 33. At some locations, construction or significant widening occurred within the three years of installation, leaving only 20 intersections for before and after statistical analysis. A control group of non-signalized intersections was also created with 67 intersections. Using SAS software, an initial negative binomial regression model was created for both the before and after signal installation periods and the control group to produce safety performance functions (SPFs). The SPFs modeled the total number of crashes for each intersection as a function of traffic: daily entering vehicles (DEV). Using the SPFs, EB was used to reduce the impact of regression to the mean. Additional variables are to be included in future analysis.

To increase the number of intersections in the analysis, a cross-classification statistical method was used to compare all signalized intersections to similar non-signalized intersections. Sixty-seven signalized intersections in Iowa were appropriate for comparison. Sixty-seven non-signalized intersections were selected from the list of comparison intersections based on minor road volume. SPFs were created for both the signalized and non-signalized intersections.

RESULTS

Results indicate that the 20 high-speed signalized intersections in Iowa had an overall crash rate of 0.79 crashes per million entering vehicles prior to installation and 0.76 after. Before installation, these intersections experienced 237 total crashes and 241 total injuries, with an average DEV of 14,300. The crash and injury severity follows (injury severity is not limited to the same crash’s severity: i.e., a minor injury may have occurred in a major injury crash):

- 2 fatal crashes with 3 fatalities
- 11 major (incapacitating) injury crashes and 16 major injuries
- 47 minor (abrasion) injury crashes and 87 minor injuries
• 60 possible (unknown) injury crashes and 135 possible injuries
• 117 property damage only crashes

After installation, these intersections experienced 253 crashes and 208 injuries with an average DEV of 15,400. The breakdown of crash and injury severity follows:

• 3 fatal crashes with 4 fatalities
• 12 major injury crashes and 15 major injuries
• 37 minor injury crashes and 60 minor injuries
• 69 possible injury crashes and 129 possible injuries
• 132 property damage only crashes

Figure 9 shows a graph of the total number of crashes by DEV for the 20 intersections used in the simple before and after analysis. The arrows show the relationship of an intersection from the before period crashes to the after period. The green vertical lines indicate a reduction in the crash rate. The red horizontal lines indicate an increase in the crash rate. The purple lines indicate approximately no change in the crash rate. The shaded curved lines are models from SAS that represent the actual crashes of the before and after periods. The diagonal lines represent equal crash rates (crashes per DEV). The graph shows that intersections below a total of 15,000 DEV tend to have a crash rate that decreases in the after period. Intersections that have DEV greater than 15,000 tend to have a crash rate that increases in the after period. These models confirm this.

Figure 9. Total number of crashes before and after signal installation
Figure 10 is a graph representing the same information as that in Figure 9; however, EB has been used to create a weighted estimate of the before crashes. Unlike the traditional analysis, EB considers the control group model and the actual number of crashes as information and weights each to get a better estimate. EB adjusts the crashes at lower DEV intersections more so than the higher DEV intersections. Naturally, the intersections with the greatest difference in crashes from the model changed a larger amount. The arrows indicate the shift from the EB before-period estimate of crashes to the actual number of after-period crashes. EB reduced the estimated effect (decreased the slope of the arrows) of installing signals, except at a few intersections. However, EB did not affect the direction of change resulting from installation, except at one intersection.

![Figure 10. Total number of crashes before and after signal installation, EB applied](image)

Results from the 67 similar expressway intersections’ cross-classification analysis in Iowa indicate an overall crash rate of 21.3 crashes per hundred million entering vehicles (HMEV) at non-signalized intersections for the latest three years of crash data. The intersections experienced 488 total crashes with 363 injuries in the same time period and an average DEV of 14,500. These intersections had a fatal crash rate of 0.47 crashes per HMEV and a fatality rate of 0.53 fatalities per HMEV. The fatal and injury crash rate was 15.1 crashes per HMEV.

The signalized intersections experienced 1,209 crashes with 637 injuries and an average DEV of 18,300. This correlates to an average overall crash rate of 84.3 crashes per HMEV. These intersections had a fatal crash rate of 0.47 crashes per HMEV and fatality rate of 0.47 fatalities per HMEV. The fatal and injury crash rate was 29.4 crashes per HMEV.
Figure 11 shows a graph of the total number of crashes by DEV for the 67 comparison intersections. Unlike Figure 9, the SPF for the signalized intersection indicates a crash rate increase at lower DEV amounts. At 22,000 DEV, the SPF for the non-signalized intersections crosses the signalized SPF and has the higher crash rate. Note that there were few non-signalized intersections with more than 20,000 DEV, whereas there were several signalized intersections with over 30,000 DEV.

![Number of Crashes at Signalized & Non-signalized Intersections](image)

**Figure 11.** Total number of crashes at non-signalized and signalized intersections

**CONCLUSION**

The results are mixed for the safety impact of installing traffic signals. The before and after analysis shows more crashes with fewer injuries occurred after the traffic signals were installed. Both the traditional and the EB results indicate that installing traffic signals reduced the number of crashes at lower DEV amounts for the 20 intersections involved in the before and after analysis. At higher DEV amounts, traffic signal installation seems to have increased the number of crashes. Upon looking at the results from the cross classification analysis, the non-signalized intersections had fewer crashes with a lower crash rate than the signalized intersections. However, the non-signalized intersections had higher fatal crash and fatality rates. As can be seen from the data and models in Figure 11, the non-signalized model indicates fewer crashes in the Iowa DEV domain.

EB had minimal impact on the results of the before and after analysis. EB reduced the crash rate change (decreased the slope) for most of the intersections. EB did not greatly increase the time needed to perform the analysis.