Safety Impact of Gateway Monuments

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Abstract

Gateway Monuments are free standing roadside structures or signage that communicate the name of a city, country or township to motorists. The placement of such monuments within state-controlled right-of-way is a relatively recent occurrence in California. As a result, the California Department of Transportation (Caltrans) initiated research to quantify the impacts that this type of signage may or may not have on crashes in their vicinity. To date, no specific research has examined the impact such features have on crashes. To determine whether these features impacted safety, the before-after study method using the Empirical Bayes technique was used, with reference groups and Safety Performance Functions adapted from existing studies, eliminating the need to calibrate new models. Results indicated that, on an individual basis, no deterioration in safety was observed at any monument site. When all sites were examined collectively (using two different scenarios), the calculated index of effectiveness values were 0.978 and 0.680, respectively, corresponding to 2.2 percent and 32.0 percent reductions in crashes. In addition to the EB method, naïve study methods (with and without AADT taken into account) were applied to the study data. Results (crash reductions) from these methods also showed that the presence of Gateway Monuments did not have negative impact on traffic safety. However, the use of EB technique should be very careful employed when adopting reference groups from different jurisdictions, as these may affect the validity of EB results. In light of these results, Caltrans may continue to participate in the Gateway Monument Program at its discretion with the knowledge that roadway safety is not impacted by monuments.

Key Words: Traffic Safety; Gateway Monuments; Empirical Bayes; Before-after Study

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1. Introduction

Gateway Monuments are free standing roadside structures or signage that communicate the name of a city, country or township to motorists. They provide communities with a means of identifying themselves while creating a favorable image. The monuments typically include the official seal or slogan of the local entity and are considered non-integral and/or non-required highway features.

The concept of Gateway Monuments is not new. For years local entities have erected signage welcoming motorists to their community. Gateway Monuments, while similar in appearance to the “marker” monuments constructed at the entrances to communities, national parks, etc., differ in a significant way. Most marker monuments are constructed in close proximity to the roadway edge. This is the result of the nature of roadway they are constructed along, which is typically lower speed (approximately 35 miles per hour or less), with a well defined travel way (curb and gutter, etc.). Secondly, marker monuments incorporate different design standards than those employed by the Gateway Monuments discussed here, particularly in terms of scale and dimensions. On the other hand, Gateway Monuments are constructed along higher speed state routes, with the result being a need for clear zone considerations to be made. The end result is that Gateway Monuments, unlike marker monuments, are set back approximately 30 feet or more from the roadway edge.

The placement of such monuments within state-controlled right-of-way is a relatively recent occurrence in California. Indeed, the inclusion of such monuments is part of a demonstration project (Gateway Monument Demonstration Program, GMDP) spanning a four year period, commencing on January 1, 2005 and concluding December 31, 2008. During the course of this project, four communities received construction approval, with installations being completed at five sites. Two additional monuments were constructed prior to the start of the program, resulting in a total of seven Gateway Monuments being installed in five California communities. The locations of these sites and images of each monument are presented in Figure 1 and Figure 2.

Monuments were constructed at the following sites:

- Willow Creek (one monument);
- Rocklin (two monuments, each located at the same interchange);
- Nevada County (one monument);
- Paso Robles (two monuments, constructed prior to start of program);
- Tehachapi (one monument).

In general, the monuments were placed along the highest traffic facility in the community, which, as is the case in most communities, happened to be a state-controlled route. The number of Gateway Monuments present in a community was not the result of any specific factor, aside from perhaps available finances. In the case of Rocklin, two monuments were constructed in conjunction with one another as part of an interchange beautification. In the case of Paso Robles, the monuments were each constructed in different locations at approximately the same time for landscaping purposes. While all of the monuments were built to welcome visitors to the community, estimates of the percentages of tourist versus local traffic passing each site would be difficult to measure and therefore were not available for this research.
Figure 1: Gateway Monument sites
Approval of monuments is based on considerations related to safety (e.g. location beyond the clear zone, provision of adequate sight distance, driver distraction), appropriateness, aesthetics, maintenance access, and the message being communicated. Before applying to the Gateway Monuments program, local entities were expected to explore other feasible alternatives to placement within the state’s right-of-way. These options include location of the monument outside the operational right-of-way, community identification on existing or proposed highway features, aesthetic treatment for an existing or proposed facility, or utilization of existing or natural topographic features in the placement of the monument (California Department of Transportation, 2005). Applicants were allowed to petition for only one monument per State Highway or Interstate per direction.

While the GMDP seeks to foster partnerships with local entities in the placement and construction of signage, there is a knowledge gap concerning how such signs affect highway safety within their vicinity. Therefore, research was needed to quantify the impacts that this type
of signage may or may not have. Such quantification would provide California Department of Transportation (Caltrans) with the necessary information to decide whether the Gateway Monuments program should continue. The research results presented here begin to address the existing knowledge gap by examining the safety performance of Gateway Monuments.

2. Similar Research

Despite the prevalence of monument signage along roadways throughout the nation (and internationally) announcing to motorists that they are entering a community, no research has been performed to date specific to the potential safety impacts of such signage. Due to this lack of monument-specific safety evaluations, literature related to the safety impacts of similar roadside features, general landscaping and additional fixed features was reviewed.

2.1. Gateway Monuments

While no safety or operational analyses were performed, Hallmark et.al. (2007) discussed several low-cost traffic calming strategies that communities may employ to address speeding issues, including elements identified as “community gateways”. This work acknowledged that such monuments may be effective in communicating to motorists that they are making a transition from a rural roadway to a city street, having distinct safety implications.

In a report published by the United Kingdom’s Department of Transport, a series of traffic calming treatments along major roads were evaluated, including community gateways. The report indicated that mean speed reductions of between 3 mph and 13 mph (with an average of 5 mph) had been observed at such gateways (Sustrans, 2008). These results indicate that there are tangible speed-reduction benefits provided by monument signage. Additional research from the United Kingdom found up to a 15 mph speed reduction for the 85th percentile of vehicles when using gateways in combination with other treatments (Department of the Environment, Transport and the Regions, 2005). This further indicates that monuments have an impact on vehicle speeds that may translate into safety benefits.

2.2. Landscape Features

Naderi (2003) investigated the effects that various roadside landscape variables within the clear zone had on driver safety. While Gateway Monuments were not among the variables, raised concrete planters, sculptures and decorative noise barriers were examined. The research found accidents decreased between 5 and 20 percent with such features in place. Furthermore, a positive effect existed from having a well-defined roadway edge, resulting in decreased run-off-the-road crashes with obstacles.

Mok and Landphair (2003) linked safety performance to corridor landscape types for four states using Fatality Analysis Reporting System (FARS) data between 1994 and 2000. The research indicated that parkways were considered to be routes which had higher aesthetic values, while freeways had paved shoulders, concrete medians and limited landscape. Comparisons of the safety performance of parallel sections of freeways and parkways by fatal crash rates and accident costs were made, with results indicating that parkway sections were significantly safer in terms of fatal crash rates per one hundred million vehicle miles travelled. Accident costs per one million vehicle miles traveled were also significantly lower compared to freeway sections.
The researchers stressed that the study did not allow for conclusions regarding which specific landscape elements contributed to the observed differences (Mok and Landphair, 2003).

Mok et al. (2006) looked at the impacts of roadside landscape improvements on safety in Texas using a before and after study of crashes as a quantitative measure of roadside greening. Results showed a significant decrease in crash rates after landscape improvements were implemented. However, the researchers do not explicitly list the landscape features that were included in the improvements, aside from a mention of trees. As a result, it is impossible to determine if any of the study sites possessed monuments or similar design features.

Finally, Tay (2009) examined the reactions of drivers to the presence of roadside memorials. These features typically consist of a cross and personal items placed on a roadside to mark the location of a fatal crash. While the author noted that such features could result in rear-end collisions involving drivers stopping at a memorial, typically features such as billboards held a greater potential for serving as a distraction. In examining the impacts of “mock” monuments (i.e. monuments set up at signalized intersections to elicit a response but where no fatal crash had occurred), it was found that red light running violations fell by 16.7 percent, while violations at comparison sites without monument increased by 16.8 percent.

2.3. Additional Roadside Features

Work by Holdridge, et al. (2005) investigated the hazards presented by fixed urban roadside objects. Models developed to estimate injury severity indicated that several roadside features had a significant impact on severities. Such features included sign posts, which increased the propensity toward non-injury crashes, and trees or poles, which increased the propensity toward fatal crashes/injuries. Consequently, the researchers stress that protecting traffic from fixed obstacles is essential for features that have shown a high propensity for resulting in higher severities.

Lee and Mannering (2002) developed statistical models of run-off-roadway crashes to isolate the factors that significantly influenced crash frequency and severity. Fixed roadside elements in the research included trees, barriers, utility and light poles, wooden sign supports, boulders, and mailboxes. Results indicated that increasing the distance from the edge of the traveled way to light poles and removing isolated trees along the roadway would reduce crash frequencies. This was not surprising, with the implications on monuments being that their location should be as far as possible from the edge of the roadway.

Troxel et al. (1991) used FARS data from 1980-1985 and National Accident Sampling System (NASS) data from 1982-1985 to examine side-impact collisions with roadside obstacles. One of the classes of obstacles examined was identified as being “Broad”. These were most similar to monuments (although such features were not explicitly listed among the examined features), with crashes into such features totaling 18 percent of all side impact collisions (Troxel et al., 1991). These results would seem to indicate that crashes with such features, at least during the period of analysis, were less prevalent. This was likely due to the limited number of large features in the roadway environment.

Note that the results presented in this section seem to contradict those presented in Sections 2.1 and 2.2. The reason for this stems from the nature of the features discussed in the previous sections. These were items that were limited in frequency (ex. monuments, planters, etc.) and which had been constructed with safety in mind (ex. clear zone areas incorporated). Conversely, the features discussed in this section are more prevalent (signs, trees, etc), and often located in close proximity to the roadway edge.
A second explanation for these differences could be considered from a human factors standpoint. The items discussed in Sections 2.1 and 2.2 represent landscaping features that are often found in locations where speed or environment (rural to urban) transitions occur. The presence of such features in a potential transition area may elicit a driver to slow down and be more cautious, producing potential safety benefits. On the other hand, it is possible that these monuments may increase the risk for drivers to be distracted by the monument, hence the request by CALTRANS to examine whether safety decreased at the location where these monuments were erected.

Finally, the work of Tay (2009), while it indicates safety benefits from roadside monuments, is not directly applicable to Gateway Monuments. This stems from the features of Gateway Monuments, which are intended solely to convey a welcoming sense of place and are located a significant distance from the roadside itself. In no way are they intended to produce a safety benefit, although such benefits may indirectly result from drivers reducing speed, etc. Conversely, roadside memorial monuments, while intended simply to serve in remembrance of a loved one, may also produce an added safety benefit of making drivers aware of locations where potential hazards may be present. As a result, while each feature represents a monument, their intention and design are likely to produce different behavioral reactions.

3. Hypothesized Impact
The hypothesized impact of Gateway Monuments on traffic safety, specifically the number of crashes occurring in their vicinity, was expected to be minimal. Of course, while no change was expected, it was also possible that an increase or decrease in crashes might occur at any of the study sites for various reasons. A decrease might be possible if the signage influences the speed of vehicles (i.e. signage serves as an informal speed transition area indicator). Conversely, from a human factors standpoint, the signage may be a distraction to motorists, resulting in an increase in crashes. While Gateway Monuments are intended to provide motorists with a brief sense of place while requiring a minimum of time to interpret the message, it is still possible that they may serve as a source of distraction, leading to a crash.

4. Study Data
To analyze the safety impact of gateway monuments, traffic flow, crashes, and other data (geometrics) were collected for the before and after monument construction periods. These data are summarized in Table 1. Five of the seven monuments were constructed along roadway segments and two were constructed at signalized intersections. The segments at Nevada County and Tehachapi were rural four-lane two-way undivided roadways and the Paso Robles Route 46 and Willow Creek sites were along rural two-lane two-way undivided roadways. The signalized intersections at the Rocklin sites were four-legged and located in urban areas. The Paso Robles U.S. 101 site was on an interchange ramp located on the periphery of town.

The construction periods for monuments varied from one to six months. Since their construction may affect motorists, crashes from the construction period were included in the after period. The construction period was included in the “after” period because of the nature of the construction activity itself. The monuments were constructed at a distance of 30 feet or greater from the roadway edge, and, unlike typically road construction work, did not constitute a work zone (i.e. no lane closures). On the other hand, once construction of the monument had begun, even in an uncompleted manner, it consisted of features that would briefly draw motorists’
attention in the same fashion that a completed monument would. For example, sites that incorporated rockwork often had these features present from the very early stages of construction. This rockwork represented a partially completed monument which was likely to attract motorist attention and possibly influence site safety.

That said, the sensitivity of the results with or without the construction period included in the “after” data were negligible. This stems from the fact that only two crashes occurred during the construction of all monuments, one at the Rocklin Westbound ramp site, and one at the Rocklin Eastbound ramp site. In addition to the construction period of the monuments, Caltrans records were examined to determine what, if any, additional construction activities occurred over the course of the years for which crash data was to be analyzed. Aside from ordinary maintenance activities (repainting pavement markings) no construction activities occurred at any site during the study period.

While the monuments are visible from each side of the road in some cases (Tehachapi), in others they are not (Willow Creek). These factors were taken into account when identifying the crashes of interest.

The crash counts in the table include all accidents (injury and Property Damage Only — PDO; no fatal crashes occurred during the study period). The total before and after crashes were 13 and 13 for segments and 23 and 22 for signalized intersections. The measured Average Annual Daily Traffic (AADT) data during “after” periods was generally higher than “before” periods except at the Willow Creek site, which saw a slight decrease. The Paso Robles U.S. 101 ramp segment experienced a moderate increase of AADT over the course of three years.
<table>
<thead>
<tr>
<th>Location</th>
<th>Length (mi)</th>
<th>No. of Lanes</th>
<th>Lane Width (ft)</th>
<th>Shoulder Width* (ft)</th>
<th>AADT **</th>
<th>Years of Data</th>
<th>Total Crashes</th>
<th>AADT **</th>
<th>Years of Data</th>
<th>Total Crashes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Willow Creek</td>
<td>0.7</td>
<td>2</td>
<td>12</td>
<td>11</td>
<td>3400</td>
<td>Aug 03 – Jul 06</td>
<td>2</td>
<td>3300</td>
<td>Aug 06 – Apr 08</td>
<td>1</td>
</tr>
<tr>
<td>Paso Robles Rt 46***</td>
<td>0.6</td>
<td>2</td>
<td>12</td>
<td>8</td>
<td>17000</td>
<td>Aug 98- Jul 01</td>
<td>0</td>
<td>20000</td>
<td>Aug 01 – Jul 04</td>
<td>4</td>
</tr>
<tr>
<td>Nevada County</td>
<td>0.4</td>
<td>4</td>
<td>12</td>
<td>10</td>
<td>27500</td>
<td>Sep 03 – Aug 06</td>
<td>5</td>
<td>34000</td>
<td>Sep 06 – Apr 08</td>
<td>1</td>
</tr>
<tr>
<td>Tehachapi</td>
<td>0.4</td>
<td>4</td>
<td>12</td>
<td>8</td>
<td>10100</td>
<td>Nov 02 – Oct 05</td>
<td>3</td>
<td>10900</td>
<td>Nov 05 – Apr 08</td>
<td>1</td>
</tr>
<tr>
<td>Paso Robles US 101***</td>
<td>0.05</td>
<td>1</td>
<td>12</td>
<td>9</td>
<td>9600</td>
<td>Aug 98 - Jul 01</td>
<td>3</td>
<td>12900</td>
<td>Aug 01 -Jul 04</td>
<td>6</td>
</tr>
</tbody>
</table>

Table 1: Summary of site data.

Segments

<table>
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<tr>
<th>Location</th>
<th>Minor AADT</th>
<th>Major AADT</th>
<th>Years of Data</th>
<th>Total Crashes</th>
<th>Minor AADT</th>
<th>Major AADT</th>
<th>Years of Data</th>
<th>Total Crashes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rocklin WB int****</td>
<td>2770</td>
<td>25000</td>
<td>May 02 – Apr 05</td>
<td>12</td>
<td>3400</td>
<td>29500</td>
<td>May 05 – Apr 08</td>
<td>7</td>
</tr>
<tr>
<td>Rocklin EB int****</td>
<td>11050</td>
<td>24000</td>
<td>May 02 – Apr 05</td>
<td>11</td>
<td>11350</td>
<td>28200</td>
<td>May 05 – Apr 08</td>
<td>15</td>
</tr>
</tbody>
</table>

* Average width for two sides of roadway
** AADT was obtained for the middle year of each before and after period
*** The Paso Robles sites were located on the east and south sides of town, respectively
**** Each of the Rocklin sites were located on opposite sides of the same interchange
5. Methodology

The purpose of this research was to investigate crash history before and after the construction of monuments and determine whether their presence negatively/positively affected traffic safety. Based on the available data, the effect of Gateway Monuments on traffic safety can be evaluated through an observational before-after study (Hauer, 1997). To do this, it was important to know about the change in safety in terms of crash counts. This change may be determined through the equations:

\[ \delta = \pi - \lambda \text{ or } \theta = \lambda / \pi \]

(1)

Where:

\[ \delta \] = crash reduction (or increase);
\[ \theta \] = index of safety effectiveness (Persaud et al., 2001);
\[ \pi \] = the predicted number of crashes in the after period without the presence of Gateway Monuments; and
\[ \lambda \] = the number of reported crashes in the after period (with a monument present).

Before-after studies can be grouped into three types: the simple (naïve) before-after study, the before-after study with control groups, and the before-after study using the Empirical Bayes (EB) technique. The selection of the study type is usually governed by the availability of the data, such as crashes and traffic flow, and whether the transportation safety analyst has access to entities that are part of the reference group. The selection can also be influenced by the amount of available data (or sample size). It is worth noting that in observational studies, the term “comparison group” is used instead of “control group” since the entities (sites for treatment) are not selected at random (Hauer, 1997).

In this study, it was easy to estimate \( \lambda \), as crash counts during the after period are known. Thus, it was essential to estimate \( \pi \) by using an appropriate technique to achieve maximum accuracy. The problem with the naïve approach is that it cannot distinguish the effects of causal factors. For example, this method does not account for large or regional changes, such as economic downturn, weather pattern or composition of vehicle fleet within the study region (which may influence the severity of crash for instance). In addition, there are causal factors that cannot be measured or are unknown but may affect safety. The Comparison-Group (C-G) method can be used to improve upon the naïve approach, but a comparison group is not available for this study because of the difficulties inherent in identifying sites that match those of Gateway Monument locations. For these reasons, the EB method was employed as it has been shown to have better performance than both the naïve and the C-G methods (Hauer, 1997), addressing problems associated with the naïve and the C-G methods (e.g., regression-to-mean (RTM), which is the potential for a high or low number of crashes to occur during any given year, but over time, for such crashes to hover around a mean annual figure), and appropriate selection of a before period. This technique has been effectively used in numerous traffic safety evaluations (Persaud et al., 2001; Persaud et al., 2003; Bauer et al., 2004; Persaud et al., 2004; Miller et al., 2006; Hadayeqhi et al., 2007; Patel et al., 2007; Srinivasan et al., 2008; Gross et al., 2008; Alfonso, 2009). The difference between this study and previous studies is that Gateway Monuments are not likely to be installed at locations with high crashes. Thus, the EB technique is not used to account for the effect of unusual high crashes in this study. On the contrary, it could be used to account for the RTM effect associated with unusually low crashes. As discussed by Park and Lord (2010), RTM “is a ubiquitous phenomenon that occurs whenever individual entities or groups of entities are measured at different time points in time unless the successive
measurements at the different time points show a perfect correlation with each other.” In other words, unless there is a perfect correlation, which is very rarely observed in practice, there will always exist RTM in before-after studies. The curious reader is referred to Stigler (1997) and Chuang-Stein and Tong (1997) for further discussions about the RTM phenomena.

5.1. Empirical Bayes Approach

Like the naïve and the C-G study, the EB before-after procedure includes four steps for estimating safety effects of a treatment (Hauer, 1997). Among the steps, an important task is to estimate the number of crashes in the after period without the safety treatment (\( \pi \)), or in this case, had a monument not been built. This section mainly introduces the EB method for the estimation of \( \pi \). For more information about the other steps, please refer to Hauer (1997).

Two pieces of information are essential to the EB approach: the accident history of an entity and knowledge about the safety of a group of untreated entities with similar traits. The group of entities with similar traits is referred to as the “reference group.” The purpose of a reference group is to capture the relationship between safety, traffic volume, and site characteristics (e.g., lane width, shoulder width). The model that depicts this relationship can then be applied to the entity of interest to estimate the associated expected crash rate.

To evaluate safety before and after the treatment for \( n \) entities with similar traits, the expected number of crashes per year for those entities (\( \{u_{B1}, \ldots, u_{Bn}\} \)) must be calculated using a Safety Performance Function (SPF). These expected numbers are further combined with observed crash counts (\( \{y_1, \ldots, y_n\} \)) in the before period to obtain the expected number of crashes per year (\( \{z_1, \ldots, z_n\} \)) before the treatment (Gateway Monuments in this case). In this study, the observed crashes for each entity and each year were available. However, AADT information was only available for the middle year of the before period. Thus, the observed crashes during the before period for each entity (\( y_i \)) were used and the AADT was assumed to be the same for each year. With this information, \( z_i \) could be estimated by the following equation using the EB technique (Hauer, 1997):

\[
z_i = w_i \cdot \bar{y}_i + (1 - w_i) \cdot u_{B_i}, \quad i = 1, \ldots, n
\]

where:

\[
w_i = u_{B_i} / (u_{B_i} + k);
\]

\[
k = \text{inverse dispersion parameter (Poisson-gamma model); and}
\]

\[
\bar{y}_i = \text{the average number of crashes per year during the before period.}
\]

In this case, \( \bar{y}_i = y_i / m_{B_i} \), where \( m_{B_i} \) is the number of years during the before period. \( w_i \) and \( (1 - w_i) \) determine the weights for observed crash data (\( \bar{y}_i \)) and the expected crash rate (\( u_{B_i} \)). This equation can be further denoted by:

\[
z_i = \frac{\bar{y}_i + k}{k/ u_{B_i} + 1} = \frac{y_i / m_{B_i} + k}{k/ u_{B_i} + 1}, \quad i = 1, \ldots, n
\]

To calculate the expected number of crashes during the after period for a group of entities (\( \{\pi_1, \ldots, \pi_n\} \)), a series of factors (\( \{r_1, \ldots, r_n\} \)) are used to account for the differences in traffic volumes and other explanatory variables between the before and after periods. Factors are estimated by:
where: 
\[ u_{Ai} = \text{The expected number of crashes during the after period for entity } i. \]

The SPF is used to calculate \( u_{Ai} \) using data collected during the after period. With these, \( \pi_i \) is computed by:
\[ \pi_i = r_i * m_{Ai} * z_i, \ i = 1, \ldots, n \]
where:
\[ m_{Ai} = \text{the number of years in the after period.} \]

The variance of \( \pi_i \) is calculated by:
\[ \text{Var}(\pi_i) = r_i^2 * m_{Ai}^2 * (k + y_i / m_{Bi}^2) / (k / u_{Bi} + 1)^2 \]

Once \( \pi_1, \ldots, \pi_n \) are obtained, \( \pi \) in Equation 1 can be estimated \( (\pi = \sum_{i=1}^{n} \pi_i) \) to evaluate safety before and after the treatment.

Instead of calculating the index of effectiveness \( (\theta) \) presented in Equation 1, an approximate, unbiased estimate of \( \theta \) was determined by the following equation (Hauer, 1997):
\[ \theta = (\lambda / \pi) / (1 + \text{Var}(\pi) / \pi^2) \]

The variance of \( \theta \) was calculated by:
\[ \text{Var}(\theta) = \frac{\theta^2 [(\text{Var}(\lambda) / \lambda^2) + (\text{Var}(\pi) / \pi^2)]}{[1 + (\text{Var}(\pi) / \pi^2)]^2} \]

5.2. Selection of Reference Groups and SPFs

As mentioned above, a reference group of entities with similar traits are required to use the EB technique for an entity (or a group of entities). In the case of this study, such reference groups were not available. Given that numerous studies have been carried out to develop SPFs for road segments and intersections, existing reference groups were chosen from the literature, with associated SPFs applied to this research. Based on the features present at gateway monument sites, SPFs for rural two-lane undivided highway segments, rural four-lane undivided highway segments, rural one-lane ramp segments, and urban four-legged signalized intersections were selected. A literature review was conducted with a focus on those four types of roadway configurations. Over ten previous studies conducted in North America were identified for urban four-legged signalized intersections SPFs (Bauer and Harwood, 2000; Lord, 2000; Lyon et al., 2005; Persaud et al., 2005; Harwood et al., 2007; Sayed and Leur, 2008) and rural two-lane and multiple-lane undivided road segment SPFs (Vogt and Bared, 1998; Council and Stewart, 1999; Persaud et al., 2004; Lord et al., 2008), and ramp segments SPF (Bauer and Harwood, 1997).

Conceptually, the role of the monuments is foremost to convey a sense of place. As a result, they were evaluated in the context of the roadway environment in which they reside. Due to the varying geometric and traffic control environments in which the monuments reside, lumping them together into one category for analysis while neglecting the contribution of the roadway environment itself, would potentially muddle the picture of the overall safety performance of each site following the addition of a monument.
In choosing appropriate reference groups and SPFs, several factors need to be considered. First, a study must provide SPFs and inverse dispersion parameters \((k)\) to apply the methodology previously discussed. Second, given the study locations of this research, reference groups in California were preferred. Applying SPFs to geographical areas other than those used in developing the models requires Accident Modification Factors (AMFs) to convert predicted accident frequency to local conditions. Third, studies using more recent years of data are preferred because the expected accident rate may be changed over a longer period due to improvements in traffic signal timing, presence of new signs and markings, and other unobserved factors. As a result, the following SPFs, developed for predicting total crashes (without crash severity), were selected for this study and are summarized in tables 2 and 3:

- For the two rural two-lane undivided highway segments, the study by Persaud et al. (2004) was chosen. Persaud’s study used data collected from 29 two-lane road segments in California and other states from 2003. The SPF developed from that work for total accidents is presented in Table 3.
- The model from the NCHRP (National Cooperative Highway Research Program) study (Lord et al., 2008) was applied to the two four-lane road segments in Nevada County and Tehachapi. This model is presented in Table 3, with data collected from 356 rural multiple-lane highway segments in California. As some of the results from this study will be incorporated into Chapter 11 of the forthcoming Highway Safety Manual (HSM), it is an ideal candidate for application to this research on account of the HSM’s intention to be applied across multiple jurisdictions nationally (Lord et al., 2008; Niessner, 2008).
- For the ramp segment, the SPF developed by the FHWA study was utilized (Bauer and Harwood, 1997). As shown in Table 3, the data were collected from 737 ramps for 3 years in the State of Washington. Given the large sample size and the number of variables (e.g., ramp type, number of lanes, ramp configuration) incorporated into the model, applying it to this study was considered reasonable.
- For the two urban four-legged signalized intersections, two SPFs were selected from the studies of Persaud et al. (2005) and Harwood et al. (2007). The first study used data from three cities (San Francisco, El Cajon, and San Diego) in California to develop models. The SPF that was developed by using the San Francisco data set was chosen for this study, as San Francisco is closer to study locations than the other two cities. The authors stated that the data collected from the three cities in California did not have full reporting of PDO crashes. For this reason, the NCHRP study by Harwood et al. (2007) was also selected. This study used data collected from 111 sites in MN and NC to develop base models, which were used to predict the safety performance of an intersection with base values of variables (e.g., 12-feet lanes, 6-feet shoulders). This study also provided AMFs for geometric design and traffic control variables to convert safety performance to local conditions. The AMFs for traffic control include left-turn lanes, left-turn signal phasing, right-turn lanes, right turn on red, and lighting. The results from this NCHRP study will be incorporated into Chapter 12 of the forthcoming HSM (Niessner, 2008). The SPFs from both studies were applied to this research and results are compared as described in the next section.
Table 2: Reference groups and SPFs for urban four-legged signalized intersections.

<table>
<thead>
<tr>
<th>Treated Locations</th>
<th>Authors</th>
<th>Geographical Areas</th>
<th>Period or Duration of Data</th>
<th>Reference Group Size</th>
<th>Regression Model</th>
<th>SPF</th>
<th>Inverse Dispersion Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rocklin EB;</td>
<td>Persaud et al. (2005) (31) *</td>
<td>El Cajon, CA</td>
<td>786 site-months</td>
<td>53</td>
<td>El Cajon: $e^{-3.95} (F_1 + F_2)^{0.53} e^{(0.279\text{minlane})} **$</td>
<td>5.263</td>
<td></td>
</tr>
<tr>
<td>Rocklin WB</td>
<td>Harwood et al. (2007) (32)</td>
<td>San Diego, CA</td>
<td>1,896 site-months</td>
<td>54</td>
<td>Negative Binomial regression</td>
<td>San Diego: $e^{-4.624} (F_1 + F_2)^{0.53} e^{(0.279\text{minlane})}$</td>
<td>4.167</td>
</tr>
<tr>
<td></td>
<td></td>
<td>San Francisco, CA</td>
<td>2,298 site-months</td>
<td>52</td>
<td>San Francisco</td>
<td>$e^{-4.477} (F_1 + F_2)^{0.53} e^{(0.279\text{minlane})}$</td>
<td>4.167</td>
</tr>
</tbody>
</table>

*: PDO crashes underreported in the study data; may result in underestimation of total crashes.

**: Minlane represents the number of left-turn lanes on the minor road.

***: Base models for total accidents. AMFs were also provided to convert predicted accident frequency to local conditions.
<table>
<thead>
<tr>
<th>Treated Locations</th>
<th>No. of Lanes</th>
<th>Authors</th>
<th>Geographical Areas</th>
<th>Period of Data Collection</th>
<th>Reference Group Size</th>
<th>Regression Model</th>
<th>SPF</th>
<th>Inverse Dispersion Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Willow Creek; Paso Robles Rt 46</td>
<td>Two lanes</td>
<td>Persaud et al. (2004) (36)</td>
<td>CA*</td>
<td>2003</td>
<td>29</td>
<td>Negative Binomial regression</td>
<td>$e^{-7.432} L^{0.834} F^{0.933} e^{(-0.036 shldwid + terrain* a)}$</td>
<td>2.702</td>
</tr>
<tr>
<td>Nevada County; Tehachapi</td>
<td>Multiple lanes</td>
<td>Lord et al. (2008) (37)</td>
<td>CA*</td>
<td>N/A</td>
<td>357</td>
<td>Negative Binomial regression</td>
<td>$e^{-6.7469} L F^{-1.1298} e^{(-0.1905 LW - 0.037 shldwid + 0.1005 INT)}$</td>
<td>2.107</td>
</tr>
<tr>
<td>Paso Robles US 101</td>
<td>One lane (ramp)</td>
<td>Bauer and Harwood (1997) (38)</td>
<td>Washington</td>
<td>1993-95</td>
<td>737</td>
<td>Negative Binomial regression</td>
<td>$e^{-9.81} (F)^{0.93} e^{(0.78<em>L+0.78</em>(off_ramp))}$</td>
<td>1.47</td>
</tr>
</tbody>
</table>

*: Data also collected from other states.

**: $a = 0$ for flat terrain; $a = 0.354$ for rolling terrain; $a = 0.269$ for mountainous terrain

***: shldwid = average shoulder width; sfwid = surface width; LW = lane width; INT = number of intersections located on the segment
6. Analysis and Results

The EB before-after approach was applied to this research with those selected SPFs. To illustrate the calculation of \( \pi_i \), the following takes the rural four-lane undivided highway segment at Nevada County (assumed entity no. 1) as an example. Using the SPF from the NCHRP study (Lord et al., 2008), the estimated numbers of crashes each year during the before and after period were:

\[
u_{B1} = e^{-6.7469} L(F_{B1})^{1.1298} e^{(-0.19053LW - 0.037shldwd + 0.10051NT)}
\]
\[= 0.001175 \times 0.4 \times (27500)^{1.1298} \times e^{(-0.190512 - 0.03712 + 0)}
\]
\[= 2.36/(\text{crashes / year})
\]

\[
u_{A1} = e^{-6.7469} L(F_{A1})^{1.1298} e^{(-0.19053LW - 0.037shldwd + 0.10051NT)}
\]
\[= 0.001175 \times 0.4 \times (34000)^{1.1298} \times e^{(-0.190512 - 0.03712 + 0)}
\]
\[= 3.00/(\text{crashes / year})
\]

Using the EB approach, the expected number of crashes per year during the before period was:

\[z_1 = \frac{y_1 + k}{k / u_{B1} + 1} = \frac{(5/3) + 2.107}{2.107 / 2.36 + 1} = 1.99/(\text{crashes / year})
\]

The expected total number of crashes that would occur during the after period had the Gateway Monument not been constructed was:

\[\pi_1 = r_i \times m_{A1} \times z_1 = (3/2.36) \times 1.67 \times 1.99 = 4.23/(\text{crashes })
\]

The variance of \( \pi \) is calculated by:

\[Var(\pi_1) = r_i^2 \times m_{A1}^2 \times (k + y_i / m_{Bi}^2) / (k / u_{Bi} + 1)^2 = 3.35/(\text{crashes }^2)
\]

The same approach was applied to other entities using the appropriate SPFs. The results of that analysis are presented in Table 4. EB estimates for intersections using the NCHRP equations (Harwood et al., 2007) included two SPFs, one for single-vehicle collisions and the other for multiple-vehicle collisions. Correspondingly, the estimated crashes during the after period had the Gateway Monuments not been constructed were the sum of single- and multiple-vehicle collisions. Four AMFs (left-turn lanes, right-turn lanes, right turn on red, and lighting) were used to convert predicted crashes to local conditions (Harwood et al., 2007). Unfortunately, information about left-turn signal phasing was not available from any study site. Instead, a conservative minimum AMF for left-turn signal phasing (0.937) was employed.

For the two intersections, the results from using the two different reference groups show that the EB estimated crashes (\( \pi \)) are significantly different, with 17.2 crashes (reference group from San Francisco, California) and 32.9 crashes (reference group from Minnesota and North Carolina) respectively. This is due in part to the fact that the San Francisco study did not fully include all PDO crashes, which affected the calibrated SPF and further impacted the estimates of \( \mu \) and \( k \).

With fewer crashes used for the negative binomial regression, \( \mu \) could have been underestimated, which could further underestimate \( z \) given a fixed \( k \). Consequently, in examining the results, estimated crashes produced using the SPF of Harwood et al. should be viewed as more accurate.

In examining estimated and observed crashes following monument construction, it is evident that no deterioration in safety occurred at any site (with the exception of Rocklin eastbound using Persaud, et al.’s SPF and Paso Robles U.S. 101). For rural two-lane sites, Willow Creek experienced roughly the number of crashes that could be expected, as did the Paso Robles Route 46.
monument site. For rural four-lane sites, Nevada County and Tehachapi experienced fewer crashes than expected, with differences of 3.23 and 2.0 crashes respectively. The Paso Robles U.S. 101 experienced slightly more crashes than the SPF predicted.

Examining the crashes at signalized intersections, the lack of inclusion of PDO crashes by Persaud et al.’s SPF becomes evident in the Rocklin eastbound results. Here, 15 crashes occurred, while the SPF estimated 8.67. Since the site is an exit ramp from I-80 with a high AADT (11,050), the majority of crashes are PDO (rear-end) and unaccounted for by that SPF.

The results generated by the comprehensive Harwood et al. model are considered more accurate. This SPF estimated 16.63 crashes compared to seven observed at the Rocklin westbound site. For the Rocklin eastbound site, 16.29 crashes were estimated, while 15 were observed. Based on these results, the observed crash history at the signalized sites following monument construction was lower than what would be expected at comparable sites.

With the estimates of $\pi$, the before-after study using the EB technique was conducted by following the steps presented in Hauer (1997). Two scenarios were used in the before-after analysis. Each used the same EB estimated crashes for the rural two-lane and rural four-lane undivided highway segments, but used different results for the urban four-legged signalized intersections, with one using the SPF from Persaud et al. (2005) and the other from Harwood et al. (2007). These results are shown in Table 5, where $\pi$ and $\lambda$ are the summed crashes for all seven sites. From the table, neither scenario shows an increase in crashes following the construction of gateway monuments. On the contrary, reductions in the number of crashes were identified. The $\theta$ values were 0.978 and 0.680, respectively, which correspond to 2.2 percent and 32.0 percent reductions in traffic crashes. Overall, the before−after study with the EB technique showed that the gateway monument sites did not deteriorate traffic safety.
Table 4 Empirical Bayes analysis results.

<table>
<thead>
<tr>
<th>Type of Entity</th>
<th>Location</th>
<th>Resource of SPF</th>
<th>Observed Crashes during the Before Period (y)</th>
<th>EB Estimated Crash Rate during the Before Period (z)</th>
<th>Observed Crashes during the After Period (λ)</th>
<th>EB Estimated Crashes during the After Period (π)</th>
<th>Variance of π</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rural two-lane undivided segment</td>
<td>Willow Creek</td>
<td>Persaud et al. (2004)</td>
<td>2</td>
<td>0.74</td>
<td>1</td>
<td>1.26</td>
<td>0.600</td>
</tr>
<tr>
<td></td>
<td>Paso Robles Rt 46</td>
<td></td>
<td>0</td>
<td>1.55</td>
<td>4</td>
<td>5.42</td>
<td>13.257</td>
</tr>
<tr>
<td>Rural four-lane undivided segment</td>
<td>Nevada County</td>
<td>Lord et al. (2008)</td>
<td>5</td>
<td>1.99</td>
<td>1</td>
<td>4.23</td>
<td>3.350</td>
</tr>
<tr>
<td></td>
<td>Tehachapi</td>
<td></td>
<td>3</td>
<td>0.92</td>
<td>1</td>
<td>3.00</td>
<td>2.276</td>
</tr>
<tr>
<td>One-lane off-ramp segment</td>
<td>Paso Robles US 101</td>
<td>Bauer and Harwood (1997)</td>
<td>3</td>
<td>0.85</td>
<td>6</td>
<td>3.36</td>
<td>3.64</td>
</tr>
<tr>
<td>Urban four-legged signalized intersection</td>
<td>Rocklin WB</td>
<td>Persaud et al. (2005)*</td>
<td>12</td>
<td>2.60</td>
<td>7</td>
<td>8.53</td>
<td>10.379</td>
</tr>
<tr>
<td></td>
<td>Rocklin EB</td>
<td></td>
<td>11</td>
<td>2.71</td>
<td>15</td>
<td>8.67</td>
<td>11.106</td>
</tr>
<tr>
<td></td>
<td>Rocklin WB</td>
<td>Harwood et al. (2007)</td>
<td>12</td>
<td>4.50</td>
<td>7</td>
<td>16.62</td>
<td>20.337</td>
</tr>
<tr>
<td></td>
<td>Rocklin EB</td>
<td></td>
<td>11</td>
<td>4.63</td>
<td>15</td>
<td>16.30</td>
<td>20.697</td>
</tr>
</tbody>
</table>

Table 5 Before-after study results.

<table>
<thead>
<tr>
<th>Statistics</th>
<th>Scenario 1*</th>
<th>Scenario 2**</th>
</tr>
</thead>
<tbody>
<tr>
<td>EB estimated crashes π</td>
<td>34.5</td>
<td>50.20</td>
</tr>
<tr>
<td>Variance(π) of estimated crashes</td>
<td>44.605</td>
<td>64.154</td>
</tr>
<tr>
<td>Observed crashes λ</td>
<td>35</td>
<td>35</td>
</tr>
<tr>
<td>Variance(λ) of observed crashes</td>
<td>35</td>
<td>35</td>
</tr>
<tr>
<td>Crash Reduction δ</td>
<td>5.5</td>
<td>15.20</td>
</tr>
<tr>
<td>Variance(δ) of crash reduction</td>
<td>79.605</td>
<td>99.154</td>
</tr>
<tr>
<td>Index of Safety Effectiveness θ</td>
<td>0.978</td>
<td>0.680</td>
</tr>
<tr>
<td>Variance(θ) of Index of Safety Effectiveness</td>
<td>0.059</td>
<td>0.024</td>
</tr>
</tbody>
</table>

*: The SPF from the study by Persaud et al. (2005) was used for intersections.

**: The SPFs from the study by Harwood et al. (2007) were used for intersections.
7. Discussion

So far, the safety evaluation of Gateway Monuments has employed the EB technique for its advantages in accounting for the RTM among others. However, the reader should be aware that there are issues that could affect the validity of EB results. The most important issue lies in the use of reference groups and associated SPFs. This study identified several SPFs from existing studies and chose the best ones for crash prediction. Reference groups from the same jurisdiction are preferred since they are more representative of the study area. In the case that a reference group is not available from the same jurisdiction, the HSM methodology is recommended through the use of AMFs to convert predicted safety to local conditions.

To validate the performance of selected SPFs, further investigation was conducted by using the naïve before-after studies method (with and without taking AADT into account) and the results are presented in Table 6. In the naïve (with AADT) method, the proportional effect on the expected crash frequency in the after period is assumed to be the same as the proportional increase in AADT. It is generally perceived that crash frequency and traffic volume have a non-linear decreasing slope relationship. Thus, the crashes in Column 8 could be overestimated given a linear relationship between crash and traffic volume, except at Site 2 with 0 crashes. For Sites 1, 3, 4, and 5, the EB crashes in Column 10 are reasonable since they are smaller than those values in Column 8. Thus, using reference groups from the same state (California in this case) produced anticipated results; using the large reference group from Washington state (Bauer and Harwood, 1997) to predict crashes at the ramp site also generated reasonable results. For site 2, the EB estimate is 5.42 crashes although there were 0 crashes in the before period, which could have been due to the RTM phenomenon (unusually low crashes in the before period). For sites 6 and 7, the reference groups were from different states and the EB crashes in Column 9 are higher than those in Column 8. Assuming no RTM effect on these two sites, the EB method could have overestimated the crashes in the after period. Finally, by comparing columns 6 and 9, it is found that in all cases with the exception of sites 4 and 5, the number of crashes regressed upwards, confirming that some sites experienced less crashes than their long-term mean, as estimated by the EB method in the before period.

In summary, all of the results (in columns 11, 12, and 13) from the three methods (naïve method without AADT, naïve method with AADT, and EB method) indicate that Gateway Monuments did not create negative impact on traffic safety. However, the use of reference groups from other jurisdictions should be very carefully considered when the EB method is applied for safety evaluations similar to that presented here.
### Table 6 Comparison of results from different methods

<table>
<thead>
<tr>
<th>Column 1</th>
<th>Site No</th>
<th>Site Name</th>
<th>AADT (Bef.)</th>
<th>AADT (Aft.)</th>
<th>% AADT Change</th>
<th>Before Crash</th>
<th>After Crash</th>
<th>After Crash (with AADT)</th>
<th>EB Crash (Bef.)</th>
<th>EB Crash (Aft.)</th>
<th>Crash Reduction Naïve (without AADT)</th>
<th>Crash Reduction Naïve (with AADT)</th>
<th>EB</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>Willow Creek</td>
<td>3400</td>
<td>3300</td>
<td>-2.94</td>
<td>2</td>
<td>1</td>
<td>1.94</td>
<td>2.22</td>
<td>1.26</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>Paso Robles Rt 46</td>
<td>17000</td>
<td>20000</td>
<td>17.65</td>
<td>0</td>
<td>4</td>
<td>0.00</td>
<td>4.66</td>
<td>5.42</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>Nevada County</td>
<td>27500</td>
<td>34000</td>
<td>23.64</td>
<td>5</td>
<td>1</td>
<td>6.18</td>
<td>5.98</td>
<td>4.23</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>Tehachapi</td>
<td>10100</td>
<td>10900</td>
<td>7.92</td>
<td>3</td>
<td>1</td>
<td>3.24</td>
<td>2.75</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>Paso Robles US 101</td>
<td>9600</td>
<td>12900</td>
<td>34.38</td>
<td>3</td>
<td>6</td>
<td>4.03</td>
<td>2.56</td>
<td>3.36</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>Rocklin WB</td>
<td>27770</td>
<td>32900</td>
<td>18.47</td>
<td>12</td>
<td>7</td>
<td>14.21</td>
<td>13.5</td>
<td>16.62</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>Rocklin EB</td>
<td>35050</td>
<td>39550</td>
<td>12.84</td>
<td>11</td>
<td>15</td>
<td>12.41</td>
<td>13.88</td>
<td>16.3</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Study Results</th>
<th>Total</th>
<th>36.00</th>
<th>35.00</th>
<th>42.01</th>
<th>45.55</th>
<th>50.19</th>
<th>1.00</th>
<th>7.01</th>
<th>15.19</th>
</tr>
</thead>
<tbody>
<tr>
<td>Segments Only</td>
<td>13.00</td>
<td>13.00</td>
<td>15.39</td>
<td>18.17</td>
<td>17.27</td>
<td>0.00</td>
<td>2.39</td>
<td>4.27</td>
<td></td>
</tr>
<tr>
<td>Intersections Only</td>
<td>23.00</td>
<td>22.00</td>
<td>26.62</td>
<td>27.38</td>
<td>32.92</td>
<td>1.00</td>
<td>4.62</td>
<td>10.92</td>
<td></td>
</tr>
</tbody>
</table>

**Note:** For sites 6 and 7, the AADT is the sum of major- and minor-street AADTs. Segments include sites 1, 2, 3, 4, and 5; intersections include sites 6 and 7.
8. Conclusion

This paper has presented the results of research that investigated whether the presence of Gateway Monuments had a detrimental impact on safety following their construction. These features are free standing roadside structures or signage that communicates the name of a city, country or township to motorists. To date, no specific research has examined the impact (if any) such features have on crashes.

To determine whether these features impacted safety, the before-after study method with Empirical Bayes technique was used, with reference groups and SPFs adapted from existing studies eliminating the need to calibrate new models for the limited sample available. Results indicated that, on an individual basis (using Harwood et al.’s comprehensive intersection SPF), no deterioration in safety was observed at any monument site. When all sites were examined collectively (using either signalized intersection SPF), reductions in the total number of crashes were observed. The calculated index of effectiveness ($\theta$) values for either scenario were 0.978 and 0.680 respectively, corresponding to 2.2 percent and 32.0 percent reductions in crashes. In addition to the EB method, naïve study methods (with and without AADT taken into account) were applied to the study data. Results (crash reductions) from these methods also showed that the presence of Gateway Monuments did not have negative impact on traffic safety. However, the use of EB technique should be carefully considered when adopting reference groups from different jurisdictions, as these may affect the validity of EB results. These results may not mean that monuments are a safety treatment; rather, they indicate that their presence was not detrimental on safety.

In light of these results, Caltrans may continue at its discretion to participate in the Gateway Monument Program with the knowledge that, for the sites examined in this analysis, roadway safety was not impacted. While this research focused on monuments present along state-controlled routes, similar sites are located along local roads. The criteria by which these sites were constructed may not be as rigorous as that employed by Caltrans, and so their safety performance may differ. In light of this, it is suggested that further research be undertaken to examine the safety performance of these sites in the future both in California and in other states. Additionally, it may be of interest, particularly with respect to urban areas, to examine driver behavior versus monument placement in future efforts. This would likely be facilitated through a driver simulator study.

Acknowledgements

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