A Full Bayesian Assessment of the Effects of Highway Bypasses on Crashes and Crash Rates

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ABSTRACT

A common contention is that the construction of highway bypasses negatively impacts the economy of local communities by reducing pass-by traffic for businesses. However, as access to specific business account records is limited, this is difficult to quantify. Another common contention is that a reduction in crashes will be achieved. The actual impact of highway bypasses in the United States has not been assessed.

This study seeks answers to the following questions with the use of a full Bayesian analysis:

- Do bypasses in Iowa affect crash frequencies and rates on the bypassed highway?
- Do bypasses in Iowa introduce a reduction of overall crash frequencies and rates, or do they merely shift crashes from the highways through the communities to the bypasses with no significant overall reduction?

The results strongly suggest that the construction of bypasses in Iowa increases traffic safety both on the main road through town and on the sum of the main road and the bypass

Key words: Bayesian—crashes—crash rates—highway bypasses—Iowa
1. INTRODUCTION

Over the past decades, several highway bypasses have been constructed throughout Iowa. Building bypasses affects a variety of elements such as traffic crashes, urban traffic densities via redirection of through traffic, and control of environmental pollution (Elvik and Vaa 2004).

Highway bypasses around rural communities in heavily traveled transportation corridors are perceived as a highly cost-effective method of improving traffic flow along non-interstate transportation routes. However, the bypassing of a central business district raises concerns among merchants and residents over possible adverse impacts on their businesses (Leden et al. 2006).

The common contention that highway bypasses negatively affect the economy of local communities by reducing pass-by traffic for businesses has been widely investigated (Andersen et al. 1993; Blackburn and Clay 1991; Buress, 1996; Hartgen 1991; WisDOT 1998; Srinivasan and Kockelman 2002). Analyzing the impacts of highway bypasses on the economy of small communities is limited by the lack of community level data for areas with population of less than 2,500.

The application of standard empirical techniques to assess the effect on local economies is limited but can be overcome by using local retail sales tax information. However, the conclusions of such analyses are only supported with site visits, surveys, and quasi-experimental results (Rogers and Marshment 2000). Furthermore, surveys of opinions held by residents of the bypassed areas regarding the bypass impact are limited and largely anecdotal and not amenable to statistical analysis (Sabol 1996).

The main aim of extending and improving road systems is to increase mobility and reduce transport costs. The effects of road design and equipment on accidents varies from one measure to another. However, highway bypasses are reported as measures that reduce the number of accidents. (Elvik and Vaa 2004)

Road planners perceive the construction of a highway bypass as a solution for heavy traffic load through towns or business districts (Srinivasan and Kockelman 2002). The expected outcome of redirecting traffic is a decrease of the negative effects of congested traffic, including frequency of accidents. Since crash data in Iowa are available for several years before and after such interventions, with the use of statistical tools it is possible to quantify the effects on traffic safety of constructing highway bypasses.

2. LITERATURE REVIEW

Forkenbrock et al. (1990) suggest that highway traffic passing through small rural towns is often slowed by congestion, traffic control devices, and poor geometry. They also suggest that rerouting long-distance commuters around small towns improves safety and reduces travel times.

The central business district of towns often assembles a mixture of pedestrians, cyclists, and motor vehicles. The accident rate in towns and cities, therefore, is usually higher than in rural areas. The high traffic volume in towns causes both environmental problems and an increased risk of accidents (Elvik and Vaa 2004).

Eagan et al. (2003) affirm that road construction and automobile dependency have been associated with community severity (i.e., the creation of a physical barrier running through the community that reduces access to local amenities and disrupts social networks), increased disturbance among residents, and social inequalities.
Figure 1. Typical highway bypass around a rural town

For much of the 20th century, transportation planners sought to improve transportation system efficiency by constructing bypasses (Sabol 1996). A highway bypass is a route that splits off and passes along the fringe of a town or city to circumvent all or most of the portions of the town or city that are developed and then ties back into the older route from which it has originated on the other side of town (Figure 1). The new route may run for a longer distance and incorporate more than one town. A highway improvement that redirects through traffic off an existing route to avoid the central business district can be considered a bypass (Sabol 1996).

When bypasses are built, the long-distance traffic is shifted outside towns and cities. This separation of local and long-distance traffic decreases the traffic volume on the main road, making it easier to introduce traffic calming measures (Elvik and Vaa 2004). Normally bypasses are built without direct access roads. The connection between bypasses and actual roads are made using high standard junctions or interchanges. Bypass roads are designed for a speed limit of at least 50 mph.

Sabol (1996) analyzed over 190 reports on the construction of bypasses in 47 states and 6 provinces in the United States. The following list summarizes the reasons for constructing bypasses cited in such reports:

- Relief of traffic congestion in the bypass community (54 sites)
- Rerouting of traffic (27 sites)
- Enhanced access to tourism resources or “downtown” (8 sites)
- Noise reduction (5 sites)
- Traffic safety improvement (4 sites)

According to Snyder and Associates, Inc. (1999), one of the reasons bypasses are built in Iowa is to concentrate a major portion of annual construction budget on the corridors between major businesses and industrial centers, also known as the commercial industrial network (CIN). In a study on highway bypasses Snyder and Associates (1999) report that:

- 64% of rural highway traffic is on the interstate and CIN system
- 82% of rural semi-truck traffic is on interstates or CIN (20% uses CIN)
- 80%+ of Iowans live within 10 miles of the interstate or CIN
- Interstate and the CIN account for only 32% of the total rural highway miles.

In many states, departments of transportation constantly evaluate the investment of resources on major road construction projects (Comer et al. 2000). Table 1 presents a list of nine safety improvement
candidate locations where the construction of a bypass or some other form of relief route has been considered by the Iowa Department of Transportation (Iowa DOT).

### Table 1. Safety improvement candidate locations in Iowa, 2006

<table>
<thead>
<tr>
<th>Needs</th>
<th>Route</th>
<th>County</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>New Route 30</td>
<td>Carroll</td>
<td>Carroll</td>
<td>Carroll Bypass</td>
</tr>
<tr>
<td>New Route 71</td>
<td>Clay</td>
<td>Spencer</td>
<td>Spencer Bypass</td>
</tr>
<tr>
<td>New Route 30</td>
<td>Crawford</td>
<td>Denison</td>
<td>Denison Bypass</td>
</tr>
<tr>
<td>New Route 63</td>
<td>Davis</td>
<td>Bloomfield</td>
<td>Bloomfield Bypass to Floris Road</td>
</tr>
<tr>
<td>New Route 61</td>
<td>Des Moines</td>
<td>Burlington</td>
<td>Burlington Bypass</td>
</tr>
<tr>
<td>New Route 71/86</td>
<td>Dickinson</td>
<td>From S. of Milford to IA. 9 (Bypass of Lakes Area)</td>
<td></td>
</tr>
<tr>
<td>New Route 30</td>
<td>Harrison</td>
<td>Missouri Valley Bypass to E. of Logan</td>
<td></td>
</tr>
<tr>
<td>New Route 30</td>
<td>Linn/Cedar</td>
<td>Mount Vernon/Lisbon</td>
<td>Mount Vernon/Lisbon Bypass</td>
</tr>
<tr>
<td>New Route 75</td>
<td>Plymouth</td>
<td>Hinton and Merrill</td>
<td>Hinton and Merrill Bypass</td>
</tr>
</tbody>
</table>

Horwood et al. (1965) analyzed the aggregate results of 45 of the 70 bypass studies from the early 1960s in the United States. Such summary of the state of bypass studies has not been duplicated nor supplanted by later research; however, the aggregated variables and results were used to derive general trends of economic impacts for those studies and not for traffic safety purposes (Comer 2000).

“From a systemwide perspective, bypasses around many of [the] rural trade centers can provide substantial benefits of reduced travel times, congestion, and accidents relative to costs” (Iowa DOT 1992, p. 34).

A meta-analysis of studies in various European countries addressing the effects of bypasses concludes that the construction of bypasses, on average, decreases the number of injury accidents by approximately 25% (Elvik and Vaa 2004). The percentage includes accidents on both the old road network and the bypass. In one of the studies on 20 bypasses in Norway, Elvik et al. (2001) observed a 19% decrease in injury accidents. The decrease was significant when a fixed effects model was used in the analysis, giving a 95% confidence interval from 5% to 30%. However, when a random effects model was employed, the decrease was rejected by significance testing, with a confidence interval between -35% and 0.4%.

According to Elvik and Vaa (2004), the effects of bypasses on the number of accidents can vary from place to place. Several factors have been found to affect accident rates. The first factor is the accident rate on the main road through town where the bypass is built. The higher the number of accidents on the main road through town, the larger the decrease in the number of accidents will be after the bypass is built. The proportion of traffic transferred to the bypass also influences the effect of the bypass. If a larger volume of traffic is shifted to the bypass, then a greater decrease in the number of accidents is to be expected. A greater decrease in the number of accidents can be attained if speed reducing measures are implemented on the main road through town that is replaced by the bypass. Finally, the design of junctions built between the old road and the bypass also influences the accident rate.

Elvik and Vaa (2004) also found that, on average, the accident rate on the old main roads increases, possibly because of the increase in speed due to the lower traffic volume. The speed limit increase on the newly constructed bypass road also raises a concern in accident severity; however, Elvik and Vaa (2004) report a Norwegian study (Amundsen and Hofset 2000) and a Danish study (Andersson et al. 2002) that assert that accident severity on the old main road did not change after a bypass road was opened to traffic.
The construction of a bypass has both mobility and environmental effects. Bypass roads increase the mobility for both long-distance and local traffic. The decrease of traffic will also make it easier for cyclists to cross roads in towns as long as the speed limits do not increase. Environmental effects include (Elvik and Vaa 2004):

- Reduced traffic noise, vibrations, air pollution, and barriers to local travelers due to the reduction in traffic volume
- Improved opportunity for introducing environmental measures in a town
- Fewer vehicle emissions due to lower traffic congestion

Eagan et al. (2003) summarized the results of studies assessing the effects of new roads on injury prevalence rates. Five of these studies addressed out-of-town bypasses with the use of before-and-after comparison of police injury reports. These bypass studies showed a general decline in the incidence of injury accidents after the opening of the new bypasses. Only two of the studies reported a statistically significant decline, and both studies were published in the 1960s (Leeming 1969; Newland and Newby 1962).

All of the bypass studies mentioned by Eagan et al. (2003) compared the incidence of injury accidents on main roads through town in the before period with the incidence of injury accidents on both old roads through town and new bypasses in the after period. The studies were all performed in European countries, two of which were in Denmark (Andersson et al. 2002; Jørgensen 1991), one in Norway (Elvik et al. 2001), and two in the United Kingdom (Leeming 1969; Newland and Newby 1962).

Eagan et al. (2003) conclude that out-of-town bypasses reduce injuries on the main road, but there is not enough evidence of the effects on secondary roads. Of the five bypass studies, only those performed in Denmark included adjacent secondary roads in the analysis of injury accidents, and each study detected statistically insignificant decreases.

Also in their review Eagan et al. (2003) found 12 bypass studies that revealed a general decrease in disturbance and community severance among residents of bypassed towns. The largest decrease in through traffic and thus in disturbance was generally experienced in smaller towns. The review shows that the disturbance level increased in the rural areas surrounding the newly constructed bypasses, thus the traffic noise was merely shifted from one place to another.

The most common methodology used for bypass studies are before-and-after analyses of previously bypassed towns and comparisons of bypassed towns to non-bypassed control towns (Comer et al. 2000). In order to obtain results that can be generalized, the sample biases need to be negligible, the before-and-after data need to be compared, the models used need to be sophisticated enough to extract meaningful information from the data and to account and control for other relevant factors, and control sites need to be included in the dataset. All cities receiving highway improvements could in fact have certain characteristics that differ from those cities not receiving such improvements (Srinivasan and Kockelman 2002).

Srinivasan and Kockelman (2002) performed a multivariate regression analysis to model the economic impacts of bypasses on small- and medium-sized communities. The study involved 23 cities in Texas, bypassed between 1965 and 1990, and 19 non-bypassed cities chosen as control cities. District traffic maps from the Texas Department of Transportation were used to infer the year when traffic first appeared on the bypasses, the year the bypasses opened, and the number of years since opening. The results of the study confirm the findings of the aforementioned review by Eagan et al. (2003) that smaller cities
experience a higher decrease in traffic after the construction of a bypass. Another important finding was that relief routes that work better from a traffic standpoint have a greater impact on local per capita sales.

Otto and Anderson (1995) note a problem that emerges when performing before-and-after studies on effects of bypasses. Since the highway bypass construction period is about two to three years, when comparing the experimental data to that of control groups (i.e., similar cities that have populations, traffic volume, and distance from metropolitan areas comparable to the bypass cities), those years of construction add bias to the statistics used to measure the data. This lag leads to an overestimated sample mean. Such means would not represent an approximation of the population mean.

Pawlovich (2003) affirms that over the past ten years fatal and injury crash rates declined in Iowa. He also claims that it is difficult to isolate the cause of such reductions in crash rates due to the wide variety of safety efforts that have been implemented over time and that better methods for determining effective strategies need to be developed. Crash rate is defined as the ratio of crashes to Annual Average Daily Traffic (AADT), for the period of interest, normalized to $10^6$ vehicles. Because of improvements in statistical computing techniques, Carriquiry and Pawlovich (2004) suggest that hierarchical Bayesian models can be used to analyze data from before-and-after studies and avoid the disadvantages of the standard regression techniques.

Pawlovich et al. (2006) used a hierarchical modeling approach on a problem similar to the one addressed in this work. They evaluated the effectiveness (in terms of improved safety) of a four-lane to three-lane conversion at various signalized intersections in Iowa. They found that the hierarchical modeling approach provided the flexibility to account for potentially relevant effects in safety beyond the potential effect of the intervention. An approach similar to the one used in Pawlovich et al. (2006), has been adopted in this work.

The paper is organized as follows: data details are described followed by a description of the exploratory analysis and modeling methodology. Analytical results are then presented and followed by interpretation of the results and a summary and conclusions.

3. DATA

This study evaluated several bypassed communities in the state of Iowa. The crash database was constructed by the Iowa DOT and was utilized to obtain traffic safety information over several years before and several years after the intervention (the construction of the bypass). The bypassed sites were compared to six cities that were scheduled to be bypassed but did not receive the intervention prior to 2005. The treated and untreated sites are distributed over 25 towns and cities in Iowa as presented in Table 2.

Most sites were observed over 24 years between 1982 and 2005, and three sites, Site 14, Site 17, and Site 18, were observed for 22 years between 1984 and 2005. Sites 1 to 19 are the bypassed sites and will be referred to as treatment or treated sites. Sites 20 to 25 were the reference sites and will be referred to as non-treatment or untreated sites throughout this work. Since several bypasses incorporated more than one town before tying back to the older route from which they originated, some of the sites include traffic safety information for a stretch of road along multiple towns (i.e., Sites 10, 16 and 17).

One concern in observational studies is sampling bias. If the sites chosen to receive a bypass had a worse safety record than those that did not receive a bypass, then the effect of the intervention on safety will be overestimated. Treated and untreated sites in this study were compared in terms of safety and other
characteristics during the years preceding the intervention, and it was found that the untreated sites appear to be safer on average than the treated sites. Anticipating that the Iowa DOT allocates its resources where the perceived is greatest, this bias is expected.

Because of the potential selection bias it is necessary to interpret the results cautiously. Sites 20 to 25 have been used as reference sites in this study with the understanding that the estimated positive impacts of the bypass on safety (if any) will likely be overstated. Selection bias is difficult to overcome without the benefit of a designed experiment where sites are randomly allocated to the intervention and control group. The hope of this study is to ameliorate somewhat the effects of selection bias by considering crash information over a period of at least 21 years at each site.

Table 2. Information on study sites

<table>
<thead>
<tr>
<th>Site</th>
<th>Site Name</th>
<th>Road Length</th>
<th>Bypass Length</th>
<th>Road + Bypass (Sum) Length</th>
<th>Completion Year</th>
<th>Treated</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Sioux City</td>
<td>11.0</td>
<td>9.3</td>
<td>20.7</td>
<td>2001</td>
<td>Yes</td>
</tr>
<tr>
<td>2</td>
<td>Alton</td>
<td>5.2</td>
<td>6.8</td>
<td>10.1</td>
<td>2004</td>
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</tr>
<tr>
<td>3</td>
<td>Storm Lake</td>
<td>10.9</td>
<td>6.4</td>
<td>17.0</td>
<td>1997</td>
<td>Yes</td>
</tr>
<tr>
<td>4</td>
<td>Pleasantville</td>
<td>4.5</td>
<td>4.2</td>
<td>7.4</td>
<td>2003</td>
<td>Yes</td>
</tr>
<tr>
<td>5</td>
<td>Prairie City</td>
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<td>5.6</td>
<td>9.4</td>
<td>1998</td>
<td>Yes</td>
</tr>
<tr>
<td>6</td>
<td>Monroe</td>
<td>4.3</td>
<td>7.4</td>
<td>10.6</td>
<td>1999</td>
<td>Yes</td>
</tr>
<tr>
<td>7</td>
<td>Otley</td>
<td>1.9</td>
<td>1.9</td>
<td>3.1</td>
<td>1999</td>
<td>Yes</td>
</tr>
<tr>
<td>8</td>
<td>Pella</td>
<td>7.2</td>
<td>10.8</td>
<td>16.3</td>
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<tr>
<td>9</td>
<td>Oskaloosa</td>
<td>5.7</td>
<td>7.8</td>
<td>13.4</td>
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<tr>
<td>10</td>
<td>Swedesburg/Olds</td>
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<td>5.3</td>
<td>9.7</td>
<td>1999</td>
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<td>11</td>
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<td>6.8</td>
<td>11.0</td>
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<tr>
<td>12</td>
<td>Blue Grass</td>
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<td>5.2</td>
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<td>2001</td>
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<tr>
<td>13</td>
<td>Marion</td>
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<td>14</td>
<td>Waverly</td>
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<td>10.9</td>
<td>17.1</td>
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<td>15</td>
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<tr>
<td>16</td>
<td>Rudd/Mason City/Nora Springs</td>
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<td>33.8</td>
<td>60.8</td>
<td>1999</td>
<td>Yes</td>
</tr>
<tr>
<td>17</td>
<td>Jesup/Raymond/Evansdale</td>
<td>23.8</td>
<td>27.3</td>
<td>47.9</td>
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<td>Yes</td>
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<tr>
<td>18</td>
<td>Denver</td>
<td>2.0</td>
<td>4.0</td>
<td>5.8</td>
<td>1996</td>
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<td>19</td>
<td>Marshalltown</td>
<td>6.6</td>
<td>9.6</td>
<td>15.5</td>
<td>1998</td>
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</tr>
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<td>20</td>
<td>Le Mars</td>
<td>5.9</td>
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<td>N/A</td>
<td>N/A</td>
<td>No</td>
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<tr>
<td>21</td>
<td>Seney</td>
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<td>N/A</td>
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<td>22</td>
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<td>24</td>
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<td>N/A</td>
<td>N/A</td>
<td>No</td>
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<tr>
<td>25</td>
<td>Hospers</td>
<td>4.3</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>No</td>
</tr>
</tbody>
</table>

The Iowa DOT provided data for each site covering the time period of the study. These data included site length (miles), crash frequency (crashes per month), traffic volume (average annual monthly traffic), vehicle miles traveled (monthly vehicle miles traveled), and monthly crash rate (monthly crash frequency per vehicle miles traveled). These data were provided separately for the through road, the bypass, and the sum of the two.

Using transportation maps from the Iowa DOT, in conjunction with plots of the monthly average daily traffic (MADT) values for each site, it was possible to infer the opening year of each bypass and the number of years since opening for each data year. Figure 2 shows a plot of the MADT for Site 1 on the
main road through town. The vertical line indicates a drastic drop in traffic volume that coincided with the year of opening of the bypass around that community as indicated by the transportation maps. Figure 3 presents the MADT through town up to the opening of the bypass, indicated by the vertical line, and the MADT on the bypass after the intervention. A careful examination of the plots reveals a large increase in MADT at Sites 5 and 17 after the construction of the bypass. These increases are expected to affect the crash frequencies and the crash rates at the respective sites.

These plots also revealed a constant pattern at each site indicating peaks of traffic during the summer months and lower traffic volumes during the winter months. Such patterns suggested the need of seasonal effects to be accounted for when analyzing crash patterns, at least in Iowa.

![Figure 2. MADT over time on the main road of Site 1](image)

![Figure 3. MADT over time on main road up to the intervention and on bypass afterwards at Site 1](image)

4. METHODOLOGY

4.1. Exploratory Data Analysis

A literature review failed to reveal substantial documentation to answer the following questions:

1. Do bypasses affect accident frequencies and/or rates on the bypassed communities?
2. Do bypasses reduce overall accident frequency and/or rates, or do they merely shift the accidents from the highway through the community to the bypass with no significant overall reduction in frequencies and/or rates?
This study employs a full Bayesian approach (Gelman et al. 2004) to answer questions one and two above. An initial exploratory analysis was performed in order to determine the form of the regression model.

Figures 4, 5, and 6 present the number of crashes per month and per mile (i.e. monthly crash frequency per mile) on the road, the main road, and then the bypass after the intervention, and the sum of the road and the bypass (sum) respectively at Site 1. The vertical line in the plot marks the time at which the bypass was completed. The solid line in the graph is a smooth estimate of the number of crashes over time. The smooth curve was obtained by fitting a non-parametric local polynomial regression with optimal bandwidth (Simonoff 1996).

Figure 4. Observed monthly crashes per mile on the main road at Site 1

Figure 5. Observed monthly crashes per mile on the main road and then the bypass at Site 1

Figure 6. Observed monthly crashes per mile on the sum at Site 1
These plots also reveal the distinct impact of seasonal effects on the number of crashes. It is necessary to account for seasonality in the model for number of crashes.

Figure 7 is a representation of the smooth curves obtained from the crash rates on the road through town (before), the bypass (after), and the sum of the road and bypass at Site 1. The number of crashes per mile decreases after the intervention, both on the road through town and on the sum of the road and the bypass, even though the traffic volume at most sites increased over time.

Distances along the old and new road were obtained with the use of the Geographic Information System software ArcView GIS 3.2 (Environmental Systems Research Institute, Inc., Redland, CA). The distances were measured from the point where the bypass branches off the old road to the point where it rejoins the old route. When calculating the distances on the sum, the portion of road at the junction of the old and new road has been taken into account in order to avoid double counting of the same stretch of road.

Based on the exploratory analysis, and the random nature of crash events, a Poisson regression model with a log-link function to associate the Poisson mean to a set of covariates was found to be appropriate. The Poisson-log normal model is essentially equivalent to a marginal negative binomial model on crash frequency. Thus, the overdispersion that is typically observed in the distribution of crashes is accounted for in the model. A set of trigonometric functions was included in the model to account for the seasonal effects on crashes.

The number of crashes per year per mile observed at each site has been calculated for the years preceding the bypass construction and following the bypass construction on Sites 1 through 19 on the main road through town. Table 3 contains such crash frequencies as well as their difference and observed percent reduction. The same values were computed and compared on the sum of the crash frequencies of the road through town after the intervention, and the bypass are also contained in Table 3.
Table 3. Observed average crashes per year per mile before and after the bypass construction

<table>
<thead>
<tr>
<th>Site</th>
<th>Crash Frequency on Road Before Intervention</th>
<th>Crash Frequency on Road After Intervention</th>
<th>Difference Road After-Road Before Intervention</th>
<th>% Reduction Road After vs. Road Before Intervention</th>
<th>Crash Freq. on Sum (Road After Intervention + Bypass)</th>
<th>Difference Sum-Road Before Intervention</th>
<th>% Reduction Sum vs. Road Before Intervention</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>12.8</td>
<td>7.7</td>
<td>-5.1</td>
<td>40.1</td>
<td>4.9</td>
<td>-7.9</td>
<td>61.5</td>
</tr>
<tr>
<td>2</td>
<td>1.8</td>
<td>1.2</td>
<td>-0.7</td>
<td>36.9</td>
<td>0.6</td>
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<td>67.6</td>
</tr>
<tr>
<td>3</td>
<td>9.6</td>
<td>4.6</td>
<td>-5.0</td>
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5. RESULTS AND INTERPRETATION

A Bayesian analysis has been performed and a hierarchical Poisson model was fitted to the crash frequencies. In the model the log mean was expressed as a function of time periods and seasonal effects. A random effect corresponding to each site was also included in the model.

5.1. Expected Crash Frequencies and Crash Rates

In order to quantify the difference in crash frequency during the before and after periods, the posterior distribution of the annual frequency per mile as well as the posterior distribution of the percent reduction in crash frequency was computed for each site. The posterior distributions were estimated for each of the sites during the year preceding the construction of the bypass and for the years following the bypass construction at Sites 1 through 19 (the treatment sites).

The posterior distributions of expected annual crash frequencies per mile on the main road for the untreated sites and for all treated sites over the years preceding and following the bypass construction are presented in Figure 8. This figure shows the effect of the bypass construction on the main road through town.
Figure 8 reveals that there is a pronounced reduction in expected annual crash frequency per mile in treated sites after the bypass construction. The posterior distributions are narrow, indicating that the posterior mean is a reliable summary of the distribution of likely values of expected crash frequencies.

Traffic volumes also appear to be rising over time at all sites; therefore, the posterior distributions of the expected annual crash frequencies on the main road per site per mile were recomputed normalizing each site to a $10^6$ AADT, obtaining the expected annual crash rate per mile. Figure 9 shows the computed posterior distribution of expected annual crash rates per mile for all treated and untreated sites over the years preceding and following the bypass construction.

Figure 9. Posterior distributions of the expected annual crash rates per mile on the main road

The posterior means and credible sets for the average expected crash frequencies were computed on the main road before the construction of the bypass and the sum of the average expected crash frequencies on
the main road through town and the bypass after the construction of the bypass. Also, the difference in expected crash frequency (main road before - sum of road after and bypass) and the percent reduction in the expected annual crash frequency per mile at each bypassed site between the after and before periods were computed.

Figure 10 presents the posterior distribution of the expected annual crash frequencies per mile for all treated and untreated sites over the years preceding the bypass construction and the sum of the crash frequencies of the road and the bypass after the construction.

Figure 10. Posterior distributions of the expected annual crash frequencies per mile on the sum

From the figures it can be noted that the reduction in expected annual crash frequency per mile on the sum is more pronounced than it was on the main road after the bypass construction and is lower than before the intervention.

The posterior distributions of the sum of the expected annual crash frequencies of the main road and the bypass per site per mile were recomputed normalizing each site to a 10^6 AADT, obtaining the expected annual crash rate per mile.

Figure 11 shows the computed posterior distribution of expected annual crash rates per mile for all treated and untreated sites over the years preceding the bypass construction and the sum of the crash rates after the construction.
6. CONCLUSIONS AND DISCUSSION

The traffic safety problem has been examined for many years with the use of various techniques. Classical statistical methods have been generally used due to their widespread understanding and ease of use. The inexpensive access to powerful computers and the development of advanced statistical techniques in recent years have allowed for Bayesian statistics to be applied to traffic safety.

This research adopted a Bayesian approach to assess the impacts of the construction of highway bypasses on the traffic safety of the combination of local and long-distance travelers driving through the bypassed location and the safety of the road travelers residing in the bypassed location. Additionally the impact on traffic safety has been assessed on the old road network consisting of the main road through town, and on the new road network consisting of the main road through town and the newly constructed bypass.

The study consisted of two parts. The first part analyzed monthly crash data for 25 sites in Iowa over a period between 1982 and 2005. Nineteen of the sites were bypassed during the study period while six sites were not bypassed. The un-bypassed sites served as reference sites. A preliminary analysis suggested the use of a hierarchical Poisson model fitted to the crash frequency observed at each site. The model took into account seasonal effects, treatment, time, and interactions for treatment and time. The association between monthly crash rate and explanatory variables was estimated with the use of a random effect included in the model. Proper but non-informative priors have been used for all parameters, and the calculations have been carried out using Markov Chain Monte Carlo methods.

The posterior means obtained were used to calculate the expected annual accident frequencies and rates at each study site. The expected annual accident frequencies and rates were compared for the periods before and after the bypass construction. Subsequently the expected annual accident frequencies and rates at each site were compared to the average of the accident frequencies and rates of the reference sites. The estimated parameters and the results from the posterior predictions suggested that the model was reasonable and fitted the data well.
Moreover the results indicated that the construction of highway bypasses in Iowa appears to be associated with an increase in traffic safety by the reduction of the number of crashes both on the old and new road networks at least in the state of Iowa and on the type of roads considered in the study. The crash frequencies on average were reduced 50% on the old road network and 62% on the new road network. The crash rates on average were reduced 33% on the old road network and 59% on the new road network.

In order to forecast the expected crashes for each of the 25 study sites, predictions were computed for each season of two selected years following the available data range: 2006 and 2008. The expected crash rates and expected number of crashes per mile during those years decrease more rapidly at bypassed sites than at reference sites.

The main objective of the second part of the study was to assess the safety of citizens of the bypassed communities and analyze data on 23 out of the 25 sites over the years between 1994 and 2005. The time range was dictated by the lack of information on driver’s provenance prior to 1994. Two of the original 25 sites were excluded from this part of the analysis due to the fact that in one site the bypass was built before 1994 and there were no accidents found involving local citizens in the other site. Five of the study sites were not bypassed and served as reference sites. For all 23 sites in this part of the study only the accidents involving residents of the sites were considered. The same approach and model used in the first part of the study was also employed here, and expected crash frequencies and rates were calculated from the posterior means obtained from the analysis.

The results of this second analysis also suggested that the model was a good fit for the data. The expected crash frequency on the old road network after the construction of the bypass on average decreased 38%. The crash rate, however, on average increased 20%. On the new road network the average crash frequency decreased on average 47%. The average crash rate on the new road network decreased on average 10%.

The increase in accidents on the old road network may be attributed to many variables, among which a reduction in traffic volume on the main road is one.

6.1. Recommendations

The results of this research are reassuring and suggest that they could be incorporated by the Iowa DOT in the decision process for selecting new bypass locations. Using available data for safety improvement locations, a preliminary and Bayesian analysis similar to those implemented in this work can produce results for forecasting the expected decrease in crash rates at those sites.

In order to assess the cause of the increase in accidents involving local citizens on the old road network, it is necessary to collect more detailed data. Traffic speeds should be surveyed on the main roads before and after the construction of a bypass in order to assess if they increase with the reduction of traffic volumes. Observational data should also be collected at certain sites in order to study driver behavior. It may be necessary to determine if the increase in accidents is related to behavioral issues. After the bypass is in place and the traffic volume decreases downtown, some drivers may feel safer and behave differently, causing them to be less cautious in their driving.

Another aspect that may lead to determining the root cause of this increase may be studying the accident severity on the main road. Severity is often related to traffic speed. If the severity of accidents decreases or remains the same on the main road, this may suggest that speeds have not increased.
This research has highlighted the impact of weather on crash frequencies and rates. Future reports should also collect information on road conditions and traffic volume by season. Road conditions may also need to be included in the police accident reports to help better understand if the increase of accidents in the colder seasons is due to an increase in traffic volume or to the road conditions.

More aspects of the impact of the construction of bypasses can be examined. This research was performed on road sections that extend for a few miles. Future research should investigate the accidents at the junction of the bypass and the road through town both at the point where the two roads split off and at the point where they tie back. This could also be done by segmenting the roads and looking at stretches of ¼ mile in length. It may also be of interest to investigate the impact of the construction of bypasses in Iowa on injury accidents by isolating those types of accidents from the crash databases.

An aspect that may improve before-and-after studies such as those described in this thesis would be to define appropriate matching criteria and identify control sites to match each bypassed site. This approach would allow for further comparison of treatment and control sites.
REFERENCES


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