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# Quantifying safety and speed data for rural roundabouts with high-speed approaches

by

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# ABSTRACT

If transportation agencies are going to move Towards Zero Deaths on their roadways, it will be essential to address the thousands of fatal and injury crashes occurring at intersections. With nearly 3,000 fatalities at rural intersections annually, better intersection designs are critical. Roundabouts are a proven safety countermeasure, but until this point the safety data for rural roundabouts on high speed roadways has been limited. This research conducted an in depth safety and approach speed data analysis for rural roundabouts on high speed roadways and provides the first published planning level crash prediction model available for rural roundabouts.

Crash analysis results showed that rural roundabouts with high speed approaches significantly reduced total crashes by 62 to 68 % and injury crashes by 85 to 88 % at nineteen rural roundabouts. Moreover, the number of angle crashes, which tend to have a higher likelihood of causing injuries at high speeds, were reduced by 83%, also a statistically significant reduction. Approach speed data proved that drivers are able to slow down in advance of roundabouts on rural roadways and the mean speeds at 100 ft from the yield line were 2.5 mph lower than mean speeds at 100 ft from the stop bar at stop controlled approaches. Additionally, a comparison between roundabout approaches with and without rumble strips showed mean speeds 4.3 mph and 3.3 mph lower at 100 ft and 250 ft from the yield line, respectively, for the approaches with rumble strips; however, the variation in speeds increased with the introduction of rumble strips.

The results of this research support decision-making to invest in an intersection alternative that lowers speeds and significantly reduces the risk of injury crashes.

Roundabouts eradicate the risk of drivers running stop signs and red lights. Roundabouts save lives.

# CHAPTER 1. GENERAL INTRODUCTION

*"Although crashes, injuries, and fatalities at intersections are not entirely avoidable, much can be done to improve the current situation." (1).*

## Introduction

A primary goal of transportation agencies is to reduce crashes and potential crashes attributable to highway system failures *(2)* as well as minimize the potential for human error and provide a forgiving intersection environment. Recent national and international initiatives such as *Toward Zero Deaths: A National Strategy on Highway Safety* and *Decade of Action* are data driven efforts focused on changing institutional and cultural attitudes towards highway safety *(3)*. If the target of zero deaths is to be achieved, the fatal and injury crashes occurring on rural two-lane highways must be addressed and reduced. During 2009, 41% of all fatal motor vehicle crashes in the United States occurred on two-lane rural roads. Six percent of all these fatal crashes occurred at unsignalized intersections on rural two-lane roads *(4)*.

Speed is often a contributing factor to intersection crashes *(5)*, however, only a modest number of studies evaluate speeds at intersections and its' relationship to safety *(6,7)*. Considering the causal factors – rural, intersection, speed, severe crashes – a solution must address each of these to be deemed successful. The modern roundabout, hereinafter referred to as roundabout, is one solution that can significantly reduce the fatal and injury crashes at intersections.

Three characteristics of roundabouts that contribute to their increased safety are reduced vehicular speeds (on all approaches), reduction in the number of conflict points and the change in the types of crashes that occur. All traffic is forced to reduce their speeds through geometry and yield to circulating traffic upon entry. Roundabouts encourage slow and consistent speeds (15 to 25mph) for all traffic. Figure 1 shows the typical characteristics of a roundabout, including splitter islands on the approaches, entry deflection, and yield on entry.

**FIGURE 1. Typical roundabout features *(8)***

The implementation of roundabouts has been successful in Europe and Australia in both the urban and rural environments for decades. The United Kingdom continues to replace many of its' traditional intersections with roundabouts and France builds approximately 1,000 new roundabouts per year *(9)*. It is estimated that there may be as many as 2,500 roundabouts in the United States but still less than 40 are on rural high-speed roadways similar to those found in this research.

Even as roundabouts have gained momentum in the United States over the past 10 years, the comprehensive research is limited to a few studies. NCHRP Report 572 *Roundabouts in the United States (10)* reports a 35 % reduction in overall crashes and a 76 % reduction in injury crashes at 55 modern roundabouts. More specifically to rural roundabouts, the research is limited to nine roundabouts where the total crash reduction was found to be 71 % and the injury crash reduction was reported at 87 % *(10).*

Despite the promise of significant reductions in crashes at rural roundabouts, reluctance remains in constructing roundabouts on rural high speed roadways. The most common concern heard is that drivers will not be able to reduce their highway speeds (free-flow) from 45, 55 or 65 mph to navigate a roundabout at 15, 20, or 25 mph. Figure 2 shows a typical approach of a rural roundabout on a high-speed roadway.

**FIGURE 2. Rural roundabout approaches**

Although roundabouts may be a “new” intersection design in the United States, rural roadways have an abundance of geometry changes that drivers experience where they must reduce their speeds. For example, roadway segments with horizontal curves often are signed with “Curve Ahead” signs or “Chevrons” and supplemented with advisory speed plates. Additionally, we also have traffic signals, stop signs and flashing warning lights at rural intersections that require a driver’s attention and ability to slow the vehicle from high speeds to low speeds or even a complete stop. Therefore, drivers do slow their vehicles for the changing conditions ahead as long as they are provided with proper warning and guidance.

## Dissertation Organization

This dissertation is based on research conducted on roundabouts on high-speed roadways and is presented as a compilation of published and submitted papers in peer-reviewed transportation journals.

Chapter 1 - General Introduction provides a general introduction to the research topic, the organization of this dissertation, and the significance of and need for the research.

Chapter 2 – Literature Review documents the existing research and information relevant to roundabouts on high-speed roadways.

Chapter 3 – Data Collection describes the gathering of crash data and the data collection plan and methodology for speed data collected at rural roundabouts and two-way stop controlled intersections.

Chapter 4 - Crash Analysis of Roundabouts at High-speed Rural Intersections is a modified version of a published research paper *(11)* documenting the before and after crash data following the installation of roundabouts and the crash characteristics for rural roundabouts on high speed roadways.

Chapter 5 – A Statistics Analysis and Development of a Crash Prediction Model for Roundabouts on High-speed Rural takes an in depth look at the statistical significance of the before and after crash data and provides the first crash prediction model specifically for rural roundabouts on high speed roadways.

Chapter 6 – Approach Speed Effects at Rural High-Speed Intersections: Roundabouts vs. Two-way Stop Control provides a comparative analysis of the approach speeds for roundabouts (without rumble strips) and the stop controlled approaches of two-way stop controlled intersections and for roundabouts with and without approach rumble strips. The variation in approach speeds was also documented and discussed.

Chapter 7 – General Conclusions provides a discussion of the research results, its potential impacts, limitations, and recommendations for future research.

Appendices are also provided for materials that are relevant to the main text but not included in the chapters.

## Need for Research

Conquering the problem of intersection fatalities and injuries continues to be a focus of national, state and local agencies. Thus far it has been difficult to find countermeasures that significantly reduce the number of severe crashes at rural intersections. One feasible alternative that has consistently gained recognition as a safety alternative to traditional intersection design in the past decade is the roundabout; however, consideration of roundabouts on two-lane high-speed (40+ mph) rural highways has not been realized to the extent that urban and suburban roundabouts have in the United States. Research is needed to document the existence of rural roundabouts on high-speed roadways and substantiate the safety benefits and their significance in reducing fatal and injury crashes at vulnerable rural two-lane roadway intersections. Furthermore, data is needed to provide hesitant agencies and doubtful citizens that drivers do slow down for roundabouts on rural high-speed roadways.

## Research Objectives

Roundabouts on rural high speed roadways have the ability to improve the overall safety of intersections and dramatically reduce the number of serious injury and fatal crashes. The objectives of this research were to:

First, quantify and document the safety benefits of rural roundabouts with high-speed approaches (40+ mph on at least one approach). As this research began, the transportation research industry and practitioners were seeking research that provided results that were ready for implementation.

Second, provide statistical significance to substantiate the safety benefits and present the first crash prediction model for rural roundabout on high speed roadways.

Third, perform a comparative evaluation of the difference in the average approach speed between roundabouts and two-way stop control intersections, neither with rumble strips, and between roundabouts with and without rumble strips.

Fourth, determine if mean speed and speed variation on roundabout approaches is an viable crash surrogate for intersection safety.

Finally, consider the crash data, more specifically, the types of crashes, contributing factors to the crashes and severity of crashes amongst the intersections and determine if a relationship between approach speed characteristics and crash data could be established.

## Expected Benefits and Research Contributions

Research included in this dissertation is some of the first documented and quantified safety research on rural roundabouts on high-speed roadways in the United States. The research contained in this dissertation provides a number of unique contributions to the body of knowledge on research related to modern roundabouts and is being sought after by researchers and practitioners alike. The rural roundabout dataset is the only one of its kind in the United States and in fact, researchers and practitioners from numerous transportation agencies in the United States (i.e. California, North Carolina, Texas, Montana, Tribal Nations) as well as Canada and Australia have used this rural roundabout research to spearhead and gain government support for rural roundabout implementation on high-speed roadways.

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# CHAPTER 2.  LITERATURE REVIEW

The literature review presented in this chapter supplements the literature within each individual paper chapter (Chapters 4, 5 and 6).  In some cases the literature cited below provides additional information about the study and in other cases it serves as background information for this research.  Within the literature below, the terms collision, accident and crash can all be used interchangeably.

## Intersections on High Speed Roadways

Eck and Sabra *(1)* studied signalized intersections on high-speed roadways in West Virginia.  Conditions that were problematic at rural intersections included speed, left turning traffic, left turning drivers' misjudgment of speed of oncoming traffic, and high volume left-turning without left-turn phasing.  Countermeasures for rear-end crashes, right angle crashes, red light violations, speeding and truck issues were placement of detectors with adjusting the yellow, activated Red Signal Ahead signs, Prepare to Stop When Flashing signs, and Flashing Signal Ahead signs.

Agent *(2)* conducted a study of sixty-five intersections on rural high-speed roadways in Kentucky identifying types of traffic control (stop signs, intersection beacon, and signal control), types of accidents, contributing factors and making recommendations for countermeasures at such locations.  Forty-seven of the intersections were signalized, sixteen were stop controlled supplemented with an intersection beacon and a majority of the intersections had turn lanes. The accident rates were similar for all traffic control devices, 1.1 to 1.2 accidents per million vehicles.

For intersections that were converted from stop control to stop control with a beacon (eleven), two intersections showed a statistically significant increase in crashes/year and two showed a statistically significant decrease in crashes/year. Similarly, conversions from stop control to signal control (sixteen) showed four intersections with a statistically significant increase in crashes/year and three showed a statistically significant decrease in crashes/year. Lastly, conversions from stop control with beacon to signal control (twenty) showed three intersections with a statistically significant increase in crashes/year and six showed a statistically significant decrease in crashes/year. The results were not consistent, especially for the signalized intersections.

Despite the inconsistency in the results additional data were reported about the types of crashes that did occur. The stop controlled and stop controlled with the beacon intersections had higher percentages of angle crashes than the statewide average, 71%, 68% and 54% respectively. The signalized intersection showed that angle, rear end and opposing left-turns each accounted for approximately 30% of the total number of crashes. The injury crashes accounted for 37%, 40% and 34% of the total crashes for stop controlled, stop controlled with beacon and signal control, respectively. The statewide average for all intersections was lower, at 24%, indicating that intersections in these environments are at higher risk for injury crashes.

Accident report comments indicated the most common events leading up to the accident were after stopping at the minor road the driver did not see the approaching vehicle (when sight distance was okay), the minor road vehicle did not stop, not enough time to stop when the signal turned red, disregard for traffic signal.

Recommendations included upgrading the signalized intersections to include a left-turn phase, modification to the change interval, all red intervals added to all signalized intersections, addition of a left turn lane, adding additional warning signs or modifying existing signs and finally that advance intersection warning is critical for drivers.

Stackhouse and Cassidy *(3)* performed a study of warning flashers at rural high speed roadway intersections in Minnesota. The results did not support the effectiveness of flashing lights on intersection safety based on driver opinion survey, analysis of accident data, and a field study. The authors concluded that adding warning flashers may not increase the safety of the intersection.

Preston and Storm *(4)* found that right angle crashes were the most predominant type of crash at rural thru-stop controlled intersections in Minnesota and that these crashes were producing 62% of the series injury crashes and 71% of the fatalities. Fifty-seven percent of the right angle crashes occurred when the vehicle stopped pulled out in front of the vehicle with the right of way and another 26% of the crashes involved vehicles that ran the stop sign, these crashes were more severe. The field review indicated that more, brighter and larger stop signs and warning signs (i.e. use of large stop ahead sign) appear to reduce the number of running the stop sign crashes. Intersections with lighting and Stop Ahead pavement marking also had less crashes. A systematic approach of these potential mitigation strategies was recommended.

Sarchet *(5)* conducted a study on the crash history of signalized intersections in Colorado. The data showed found that accidents increased at 75% of the 112 locations that were converted to signals. Injury accidents increased at 63% of the intersections. Rural intersections included in this data set also showed a 63% increase in injury accidents.

As a part of the NCHRP Report 613, *Guidelines for Selection of Speed Reduction Treatments at High-Speed Intersections (6)*, three speed reduction treatments were evaluated in a before and after study. Dynamic warning signs, transverse pavement markings and transverse rumble strips each showed a reduction in the approach speeds however only the first two treatments indicated safety improvements.

## Roundabouts

Well designed roundabouts create safer intersection environment for all users *(7,8,9)*. Roundabout change how a driver approaches the intersection and how they navigate through the intersection. The reasons roundabouts create a safer intersection are three-fold:

1. All vehicles are travelling, on average, 15 to 25mph, through the intersection;
2. The number of vehicle-vehicle conflict points are one-quarter that of a traditional four approach intersection, as shown in Figure 1, therefore reducing the probability of a crash; and
3. The types of crashes that occur have changed from high speed, right-angle (left turns) crashes and are replaced with lower speed sideswipe crashes and rear end crashes.

The international and now national roundabout safety research verifies the effectiveness of reducing injury crashes in all driving environments. A sampling of the roundabout safety research follows.

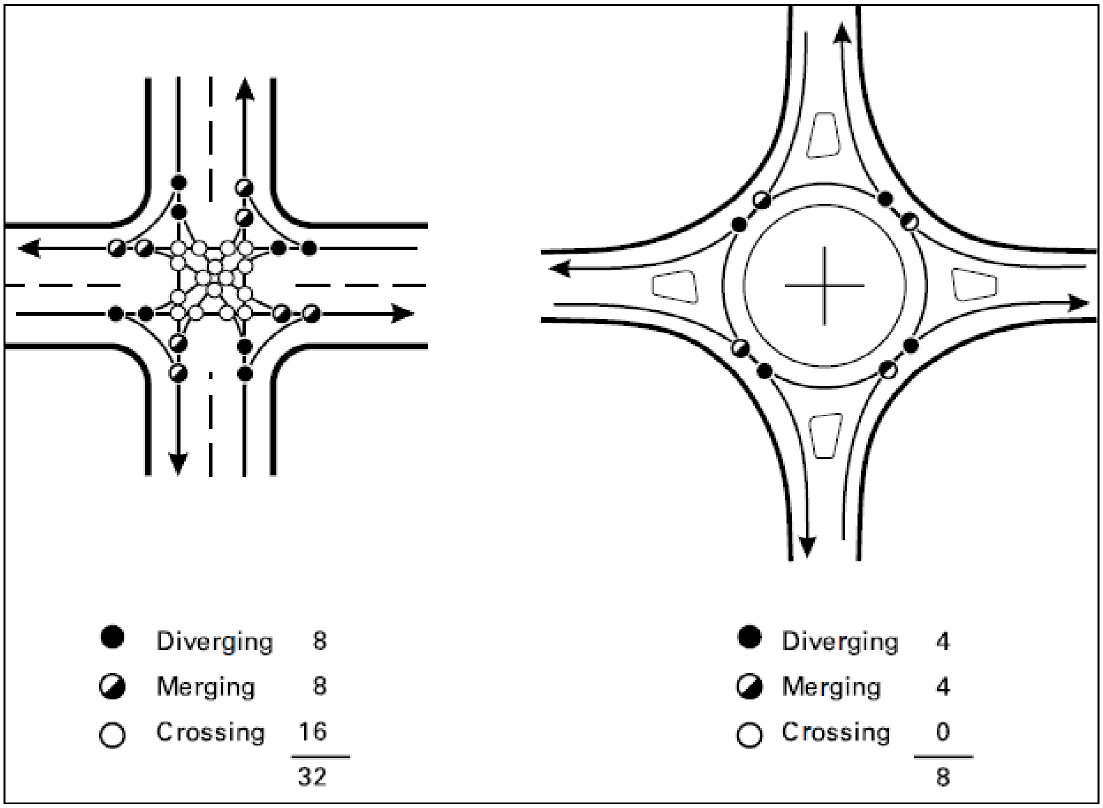


**FIGURE 1. Vehicle-vehicle conflict points (Source: 2000 FHWA Guide, Exhibit 2-3)** ***(7)***

Accident research on thirty-eight roundabouts, predominantly mini- and small-roundabouts, in the Greater London, England area conducted by Lalani *(10)* found a 39% reduction in vehicle accidents. The number of rear-end and single-vehicle crash types remained virtually unchanged after the roundabouts were implemented but cross-road and right-turning (US left turning) crash types were eliminated entirely. The average before and after periods for this study were only 19 months which may not take into account regression to the mean. However, the elimination of the two types of conflicts (cross-road and right-turning) that have the greatest potential to cause the most injury is a significant finding. The number of cross-road crash types dropped from 108 in the before condition to zero in the after condition and right-turning (US left-turning) crash types dropped from 42 to zero in the after condition.

*Accidents at 4-arm Roundabouts (11)*, provides an in depth safety study of eighty-four roundabouts in the United Kingdom. Crash frequencies ranged from 2.36 to 4.38 crashes/year at the roundabouts with approximately 16 % of those crashes being injury crashes. Furthermore, at eleven roundabouts on high speed roadways, the crash history indicated only four fatal and injury crashes per 100 million vehicles. Figure 2 shows a photo of a rural roundabout in the United Kingdom. This comprehensive safety research on roundabouts was monumental, in that many countries used these results, as the basis for designing and constructing roundabouts. (Note: by comparison, the AASHTO Highway Safety Manual *(12)* reports that fatal and injury crashes account for nearly 41% of all crashes at traditional intersections on rural two-lane roadways.)

**FIGURE 2. Rural roundabout in the United Kingdom (driving on left hand side)**

A study was conducted near Sydney, Australia to assess the accident frequency and severity of crashes after the installation traffic signals (11 sites) and roundabouts (13 sites) over a two-year before and after period *(13)*. The results indicated significant reductions in accident frequency for traffic signals and roundabouts; however the performance of the roundabouts showed a much higher reduction, 71% versus 35%. Accident severity was evident at the roundabout intersections but not at the 95% significance level. The study showed that seven fatalities occurred at the signalized locations in the after period and one fatal accident was reported at the roundabout intersections. Signals and roundabouts both reduced accident frequency but not to the same degree.

Although roundabout construction began in the United States in the mid- 1990's, it wasn't until 1997 and 1998 that roundabout safety data emerged in the literature in the United States. In an article in TR News, *(14)* made reference to the limited number of roundabouts in the United States that disallowed extensive safety analysis to be performed but noted that similarities in accident prediction models from the United Kingdom and United States for conventional intersections may allow the United States to conclude that roundabouts have the potential to reduce crashes as they do in the United Kingdom.

In NCHRP Synthesis of Highway Practice 264: *Modern Roundabout Practice in the United States,* Jacquemart *(15)* noted that roundabouts promote an environment for the driver to have a "higher level of responsibility" and a reduced "level of frustration" while driving. Additionally, he reported that European studies indicate that the safety benefits are greatest for single-lane roundabouts in rural conditions.

A review of 50 safety audit reports of roundabouts resulted in a summary of key issues at roundabouts in New Zealand *(16)*. Inadequate signing (location, appropriateness, size and quantity) was noted as the most common problem by safety auditors. The signing problems may have contributed to poor driver guidance, high approach speeds and poor driver recognition of intersection control. Poor signing, inadequate or inappropriately located, (relating to rural environments) can lead to confusion for unfamiliar drivers seeking a particular location and affect the ability of the driver to anticipate the intersection. The authors suggest providing larger warning signs on high speed approaches and/or increasing the number of signs (i.e. one on each side of the road) and installing large advance directional signs.

Furthermore, the New Zealand study found that lack of recognition of the central island may cause loss of control, rear end, or failure to yield crashes. Raising the central island to improve its visibility, chevron signs in the central island, lighting and proper design of the splitter island are all suggestions to alleviate the problems. Inadequate deflection on approach to roundabouts can lead to a failure to yield to circulating vehicles, rear end collisions and loss of control accidents. Some solutions suggested are moving the center island, increasing the diameter, modifying the approach geometry, and increasing the deflection by realignment of the curbs and splitter island.

The Swedish Road Administration commissioned a study on accident and injury risks at roundabouts *(17)*. The study performed a speed analysis in 536 roundabouts, a safety (of motorists) analysis of 182 roundabouts and safety of cyclists and pedestrians in 72 roundabouts. Nineteen percent of the accidents at roundabouts (over 563 accident years) were injury accidents – no fatalities – and 85% of those had only slight injuries. Still, the study found that the number of accidents was directly proportional to the posted speed (within the roundabout) and the number of injured had a quadratic relationship with posted speed (within the roundabout). Recommended speeds (i.e. advisory speeds) are not posted in Sweden. A new prediction model was presented to estimate predicted accident rate. The explanatory variables included number of intersection legs, posted speed and number of circulating lanes. The model showed a reduction (14%) in accidents at roundabouts with three legs versus four legs, and increase (88%) in accidents when the posted speed is 70 km/hr and an increase (20%) in accidents if there are two circulating lanes.

Persaud et al. *(18)* conducted an empirical Bayes observational before-after study on twenty-three intersections in the United States. The results indicated a 40% reduction in all crashes and an 80% reduction in injury crashes. Five rural, single-lane roundabouts experienced a 58% reduction in total crashes and an 82% reduction in injury crashes. These crash reductions were consistent with international findings.

A case study example, where roundabouts were considered was documented by Rosales et al. *(19)*. An alternative analysis for two intersections along a corridor in Washington County, OR, where there was a high number of crashes over a five-year period. The intersection alternative needed to improve safety (i.e. reduce crashes), provide room for large trucks and agricultural equipment and minimize the environmental impacts (wetlands, farm land). Two roundabout and two traditional intersection alternatives were analyzed. A project advisory committee was established to recommend the best alternative based the criteria above. Roundabout alternatives were chosen for both intersections based on safety and the ability of the roundabout to improve intersection operations and provide priority given to major traffic movement.

Thomas and Nicholson *(20)* discuss many of the design features of rural roundabouts in New Zealand that maintain their level of safety. 1.) Geometric design should allow for only 30mph (50kph) circulating speeds in rural environments and minimize the relative speeds between vehicles, as many rural roundabouts can potentially have a higher number of large trucks. 2.) Low absolute speeds for all drivers allowing them to react to potential crashes. 3.) Adequate deflection to keep speeds low and conflicting speeds consistent. 4.) Appropriate approach, entering and intersection sight distances. 5.) Avoid inducing curvature (reverse curves) on the approaches 6.) Splitter islands should be at least 60m in length but desirable to have it the length of the deceleration distance on the approach to the roundabout. 7.) Lighting is required but the lighting configuration should not be misleading. 8.) Installation of transverse pavement markings to induce speed reduction on the approaches, where necessary. 9.) Driver education. The study also indicates an 86 to 100% reduction in injury crashes at two rural roundabouts over a 4.5 year and 3 year period, respectively, after the roundabout was constructed

Another early case study for roundabout implementation was when Washington State Department of Transportation (WSDOT) considered a roundabout as an intersection alternative for a high-speed, rural intersection in King County *(21)*. WSDOT designers compared crash rates for rural roundabouts in the United Kingdom verses signalized intersections on high speed roadways in King County. The predicted injury crash comparison indicated that the roundabout would outperform the existing intersection control and a signalized intersection, as shown in Table 1. A roundabout was constructed in 2004 and the number of injury crashes dropped from 3.75 per year to 2 per year.

**TABLE 1. Injury Accident Statistics – Roundabouts vs. Signals *(21)***

| **Category** | **Injury Accidents per 100 Million Vehicles** | | | | | |
|---|---|---|---|---|---|---|
| | Fatal | Serious | Slight | Total | Number of Sites | Average Daily Traffic |
| Roundabouts 50–70 mph[1] | 0.19 | 3.8 | 24.7 | 28.7 | 11 | 27,800 |
| Signals 45-55 mph[2] | 0.56 | 11.8 | 39.2 | 51.5 | 8 | 20,400 |
| Novelty Hill Road, Existing[2] | 0.0 | 29.9 | 62.3 | 92.2 | 1 | 13,700 |
| Projected Roundabout[3] | 0.13 | 2.54 | 16.52 | 19.19 | | |

[1] LR1120 "Accidents at 4-arm Roundabouts"
[2] WSDOT Accident Records and WSDOT Traffic Counts
[3] Projections from RODEL Ltd.

Johnson and Flannery *(22)* evaluated speeds at eleven roundabouts in high-speed environments in order to develop models to estimate how design may affect safety and operations. (Five of these locations were considered actual rural roundabouts based on this current study.) The speeds collected were within 250 ft of the yield line. The findings showed that the approach half-width, effective flare length and posted speed limit are all statistically significantly correlated to mean and 85th percentile approach speeds. Furthermore, inscribed circle diameter, posted speed limit, effective flare length and approach half width are statistically significant estimators of approach and entry speed differentials.

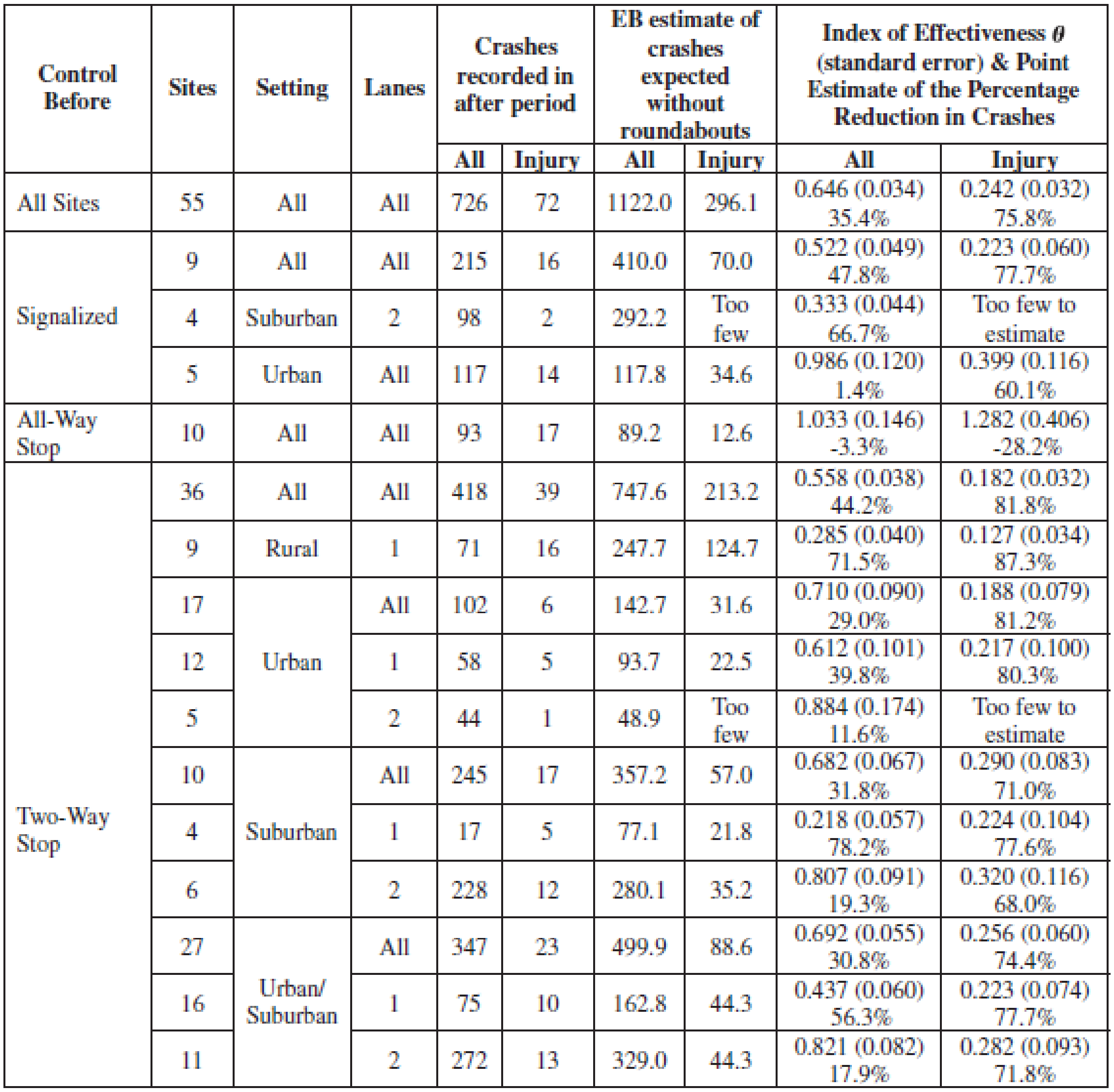
A before and after roundabout comparison of 122 intersections in Belgium by Antoine *(23)* showed a 42% decrease in injury crashes and 48% decrease in series accidents. The reduction varied by environment, 15%, 46% and 50% reduction in urban, suburban and open country, respectively. A reduction of 15% of crashes was observed at all other intersection types. Traffic signals in the open country (rural environment) showed a crash frequency that was twice as high as roundabouts. In 56% of the crashes a vehicle was turning left. The researchers state that traffic signals should be avoided in the open country. Obstacle (or fixed object) collisions were the most common (59%) for the open country (rural) environment. The central island, splitter island and lighting posts were the most common objects hit. These crashes were attributed to poor decisions made on the approaches and high approach speeds. Roundabouts provide a safe intersection in open country.

Turner and Roozenburg *(24)* suggest that the evolution of roundabout design standards has provided better roundabout designs in recent years, however that infers that there are many roundabouts in operation that have fundamental deficiencies which invoke several safety concerns, such as inadequate deflection. Roundabouts have a particularly good safety record in high-speed environments compared to traditional intersection traffic control in New Zealand. It is thought that there is a relationship between accidents, speed, traffic volume and sight distance. The authors found that roundabouts with approach speeds higher than 70km/h (44 mph) had 35% more reported injury crashes than roundabouts with approach speeds less than 70 km/h. It is unclear if these roundabouts with high-speed approaches represented both rural and urban environments and both single-lane and multi-lane roundabouts. The authors suggest that roundabout design standards that encourage reducing both entering and circulating speeds would be beneficial.

The first comprehensive safety study in the United States was published in 2007 as NCHRP Report 572 Roundabouts in the United States *(8)*. Overall, a 35 % reduction in total crashes was realized at 55 roundabouts and a 76 % reduction in injury crashes. The nine rural locations showed a 72 % reduction in total crashes and an 87 % reduction in injury crashes.

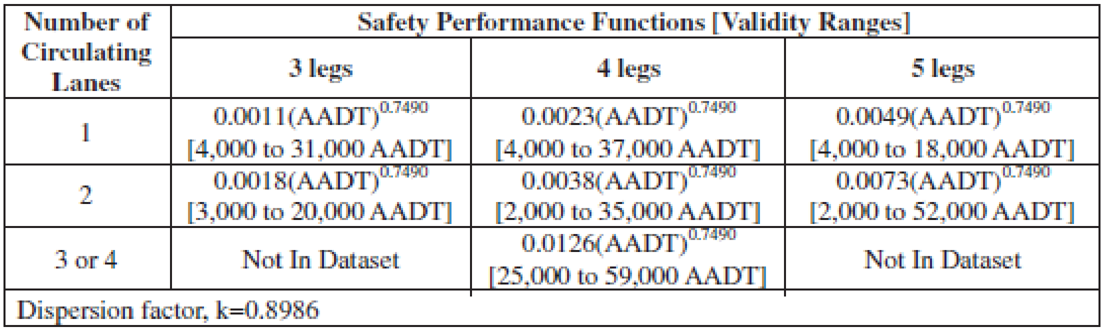
Table 2 shows a copy of the results from this research. Furthermore, this research also provides the first United States based safety prediction models for roundabouts as shown in Table 3. These models do distinguish between number of approach legs and number of circulating lanes; it does not distinguish between environments, urban, suburban or rural.

**TABLE 2. Before and After Safety Analysis Results from NCHRP Report 572, Table 28 *(8)***

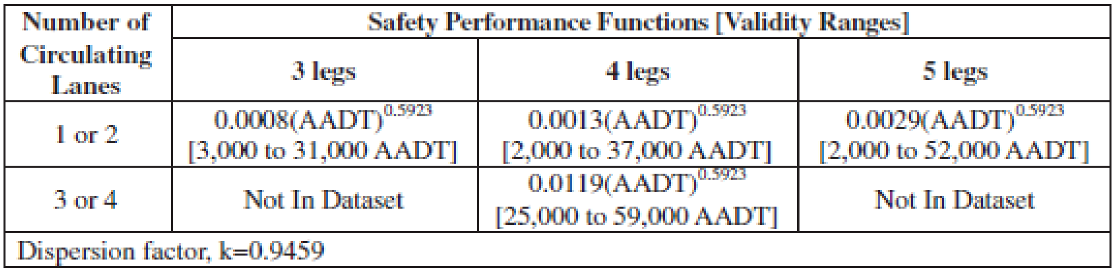


| **Control Before** | **Sites** | **Setting** | **Lanes** | **Crashes recorded in after period** | | **EB estimate of crashes expected without roundabouts** | | **Index of Effectiveness $\theta$ (standard error) & Point Estimate of the Percentage Reduction in Crashes** | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | **All** | **Injury** | **All** | **Injury** | **All** | **Injury** |
| All Sites | 55 | All | All | 726 | 72 | 1122.0 | 296.1 | 0.646 (0.034)<br>35.4% | 0.242 (0.032)<br>75.8% |
| Signalized | 9 | All | All | 215 | 16 | 410.0 | 70.0 | 0.522 (0.049)<br>47.8% | 0.223 (0.060)<br>77.7% |
| | 4 | Suburban | 2 | 98 | 2 | 292.2 | Too few | 0.333 (0.044)<br>66.7% | Too few to estimate |
| | 5 | Urban | All | 117 | 14 | 117.8 | 34.6 | 0.986 (0.120)<br>1.4% | 0.399 (0.116)<br>60.1% |
| All-Way Stop | 10 | All | All | 93 | 17 | 89.2 | 12.6 | 1.033 (0.146)<br>-3.3% | 1.282 (0.406)<br>-28.2% |
| Two-Way Stop | 36 | All | All | 418 | 39 | 747.6 | 213.2 | 0.558 (0.038)<br>44.2% | 0.182 (0.032)<br>81.8% |
| | 9 | Rural | 1 | 71 | 16 | 247.7 | 124.7 | 0.285 (0.040)<br>71.5% | 0.127 (0.034)<br>87.3% |
| | 17 | Urban | All | 102 | 6 | 142.7 | 31.6 | 0.710 (0.090)<br>29.0% | 0.188 (0.079)<br>81.2% |
| | 12 | | 1 | 58 | 5 | 93.7 | 22.5 | 0.612 (0.101)<br>39.8% | 0.217 (0.100)<br>80.3% |
| | 5 | | 2 | 44 | 1 | 48.9 | Too few | 0.884 (0.174)<br>11.6% | Too few to estimate |
| | 10 | Suburban | All | 245 | 17 | 357.2 | 57.0 | 0.682 (0.067)<br>31.8% | 0.290 (0.083)<br>71.0% |
| | 4 | | 1 | 17 | 5 | 77.1 | 21.8 | 0.218 (0.057)<br>78.2% | 0.224 (0.104)<br>77.6% |
| | 6 | | 2 | 228 | 12 | 280.1 | 35.2 | 0.807 (0.091)<br>19.3% | 0.320 (0.116)<br>68.0% |
| | 27 | Urban/ Suburban | All | 347 | 23 | 499.9 | 88.6 | 0.692 (0.055)<br>30.8% | 0.256 (0.060)<br>74.4% |
| | 16 | | 1 | 75 | 10 | 162.8 | 44.3 | 0.437 (0.060)<br>56.3% | 0.223 (0.074)<br>77.7% |
| | 11 | | 2 | 272 | 13 | 329.0 | 44.3 | 0.821 (0.082)<br>17.9% | 0.282 (0.093)<br>71.8% |

**TABLE 3. Safety Prediction Model for Total and Injury Crashes at Roundabouts from NCHRP Report 572, Tables 19 (top) and 20 (bottom)** ***(8)***



| Number of Circulating Lanes | Safety Performance Functions [Validity Ranges] | | |
|---|---|---|---|
| | **3 legs** | **4 legs** | **5 legs** |
| 1 | $0.0011(AADT)^{0.7490}$<br>[4,000 to 31,000 AADT] | $0.0023(AADT)^{0.7490}$<br>[4,000 to 37,000 AADT] | $0.0049(AADT)^{0.7490}$<br>[4,000 to 18,000 AADT] |
| 2 | $0.0018(AADT)^{0.7490}$<br>[3,000 to 20,000 AADT] | $0.0038(AADT)^{0.7490}$<br>[2,000 to 35,000 AADT] | $0.0073(AADT)^{0.7490}$<br>[2,000 to 52,000 AADT] |
| 3 or 4 | Not In Dataset | $0.0126(AADT)^{0.7490}$<br>[25,000 to 59,000 AADT] | Not In Dataset |
| Dispersion factor, k=0.8986 | | | |



| Number of Circulating Lanes | Safety Performance Functions [Validity Ranges] | | |
|---|---|---|---|
| | **3 legs** | **4 legs** | **5 legs** |
| 1 or 2 | $0.0008(AADT)^{0.5923}$<br>[3,000 to 31,000 AADT] | $0.0013(AADT)^{0.5923}$<br>[2,000 to 37,000 AADT] | $0.0029(AADT)^{0.5923}$<br>[2,000 to 52,000 AADT] |
| 3 or 4 | Not In Dataset | $0.0119(AADT)^{0.5923}$<br>[25,000 to 59,000 AADT] | Not In Dataset |
| Dispersion factor, k=0.9459 | | | |

Mandavilli et al. *(25)* studied twenty-nine single-lane roundabouts and nine two-lane roundabouts in Maryland that were constructed from 1993 to 2005. Run-off-road, rear end, entering-circulating and sideswipe crashes accounted for 97% of the 149 total crashes. Of those, 50% were single vehicle run-off-road and “unsafe” speeds were reported at 50% of those crashes. 42% of these crashes occurred on the entrance approach. Rear end crashes accounted for 34% of the crashes and entering-circulating (i.e. failure to yield) crashes for 13%. Field observations suggest that speed related issues may have resulted from lack of advanced signing, insufficient street lighting, wide approach lane widths, lack of conspicuous central island landscaping, and short splitter island lengths. The authors suggest several low costs solutions to encourage speed reduction prior to the roundabout, some include enhanced landscaping, reflective signs on the central island, extension of the splitter island, and enhanced street lighting.

Kennedy *(26)* summarizes the international safety experience of roundabouts in eight countries. The crash frequency ranged from 0.05 to 8.71 crashes per year for all intersection environments and traffic volumes. In the United Kingdom, a 2005 study of 1,162 roundabouts found that only 7% of the crashes resulted with a fatal or serious injury, down from 16% reported in 1984 by Maycock and Hall.

## Roundabout Guidance

Until recently the available roundabout design and guidance has primarily relied on international experience. The United Kingdom Department of Transport published *Geometric Design of Roundabouts*, in 1993 *(27)*, followed by the *State of the Art Review: The Design of Roundabouts* in 1995 *(28)*. These documents were the basis of roundabout design guidelines published by the Federal Highway Administration in 2000 *(7)*, known as *Roundabouts: An Informational Guide* or the FHWA Guide.

In the years that immediately followed the publication of the 2000 FHWA Guide *(7)*, it is estimated that between 1,000 and 1,500 roundabouts were constructed in the United States. With each of these roundabouts, more experience was gained and best practices for roundabout design quickly materialized. The research project, *NCHRP 3-65 Roundabouts in the United States* was already underway documenting these best practices, collecting safety and operational data and refining the design guidance for roundabouts in the United States. Other design guidance became known during this time that helped shape applications and designs in the United States, such as the Wisconsin Department of Transportation - Facilities

Development Manual *(29)*, Kansas Department of Transportation Roundabout Guide *(30)* and Australia's Department of Main Roads Road Planning and Design Manual *(31)*. This research and publications paved the way for the update to the 2000 FHWA Guide, which was published as NCHRP Report 672 *Roundabouts: An Informational Guide, Second Edition (9).*

Interestingly, all of the guidance mentioned above, indicated significant benefits of roundabouts on rural high speed locations, yet this application is one of the slowest to emerge in the United States. Exceptions to this slow start were the Maryland State Highway Administration, who constructed some of their first roundabouts in the mid 1990's and several of them were rural applications and followed by the Kansas Department of Transportation in 2001 and Washington State Department of Transportation in 2004. To date the Wisconsin Department of Transportation, has constructed the most rural roundabouts, almost all of them being constructed after 2005.

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# CHAPTER 3.  DATA COLLECTION

This research was conducted with limited funding and resources.  In addition to the limited funding for this project, at the time of data collection, less than thirty roundabouts in the United States and Canada could be identified as candidate intersections for this research.  Both safety records and speed data would be collected for this research.

The definition of rural can be inconsistent and it is an important component of this research.  The United States Department of Agriculture has multiple definitions for a non-metro area with the most rural category defined as “completely rural or less than 2,500 urban population, not adjacent to a metro area” *(1)*.  The photos in Figure 1 show examples of the rural environment in the context of the intersections included in this research.  Rural roundabouts can vary considerably due to roadway and land use considerations and may account for some variation in safety experience.

**FIGURE 1.  Examples of rurality (Photo credit: Kansas DOT - left)**

It was understood that the number of intersections would not be as robust as desired but considering this was the first research on rural roundabouts on high speed roadways in North America the effort was deemed to be necessary and appropriate.  Also knowing that in the future this data would be supplemented with new data and rural roundabouts on high-speed roadway with continue to be evaluated for their safety effectiveness.

Data collection efforts were consistent with similar research at high speed rural intersections *(2,3,4,5)* with the appropriate modifications made specifically for this research.

Additional details about the data collection are included in Chapters 4, 5, and 6.

## Safety and Intersection Data

Twenty-nine roundabouts in thirteen jurisdictions were originally considered for this research effort. A list of these intersections can be found in Appendix A. A site visit was conducted at nineteen of the intersections and the remainders were evaluated for consistency with aerial imagery. Several locations were immediately dismissed because they were new intersections (i.e. there was no intersection before) and no before data was available for the safety evaluation. Other intersections were removed because it was determined that they did not meet the rural environment definition.

Originally, seventeen roundabout intersections were selected for the safety evaluation (These results are presented in Chapter 4 of this dissertation). Subsequently, three additional intersections were added to the list but only nineteen qualified intersections for the statistical analyses and crash prediction model, as presented in Chapter 5 of this dissertation. Ultimately, this research evaluated crash data from eight different transportation agencies. The intersection locations and selected before and after aerial images are included in Appendices’ B and C. Crash data reporting practices and availability from state to state and jurisdiction to jurisdiction was very improbable. Crash reports, crash data summaries, crash diagrams, and historic traffic volume data were requested from each of the agencies in order to evaluate the safety data at the intersections, before and after roundabout implementation.

As is commonly known in the safety profession, the reporting of crashes is not consistent (i.e. not every jurisdiction uses KABCO) and injury crash reporting is subjective to the officers' judgment at the scene of the crash. Whenever possible, the crash data summaries were supplemented with the crash reports to provide a better understanding of the crash and circumstances that lead to the crash.

The data set provided crash records of 511 total crashes before and 212 total crashes after the installation of the roundabouts. Figure 2 shows the crashes per year before and after for total and injury crashes. Ninety-eight data years were available during the before and after periods, however both the before and after years varied. More importantly, the data set included 299 injury crashes before (12 fatal) and 44 injury crashes after (0 fatal).

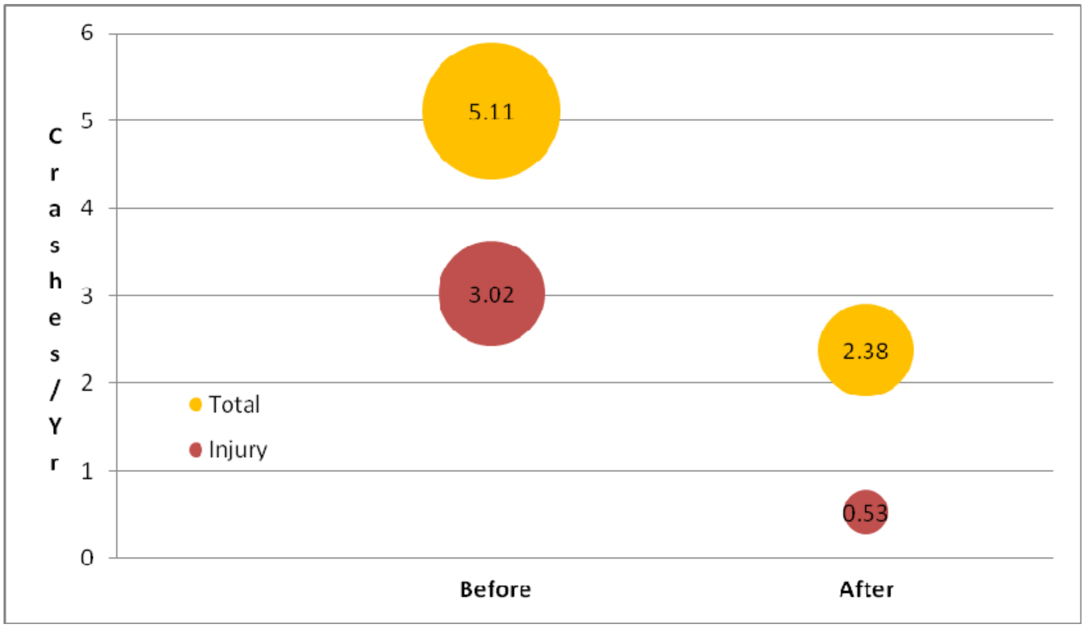

**FIGURE 2. Crashes per year before and after the installation of roundabouts**

Interesting findings after reviewing the crash data were the limitations of the crash reporting documents in terms of accurately representing the types of crashes that occur at roundabouts. Some crashes at the roundabout were coded angle crashes when they would have been better represented at sideswipe crashes based on the sketch and anecdotal information on the crash report. Additionally, the fixed object crashes also stood out as and required more information. The crash reports indicated that many of the fixed object crashes were when vehicles became disabled or stuck after hitting the curb on the center island of the roundabout. This highlights the importance of having good crash reporting documents and appropriate training for officers to ensure accurate crash records.

Anecdotal information about the intersections and construction plans were also obtained for reference and use during the speed study. Example plan sheets are in Appendix G. Advanced traffic control signing and rumble strip locations were also needed and then confirmed in the field.

## Speed Data

Speed data collection was considered for all of the roundabouts selected as part of the safety analysis, as discussed above, and two-way stop controlled intersections that were similar to the before condition of the roundabouts sites and crash data was available. The research team would need to have the cooperation of the owning agency to collect data within the right of way and be in close proximity to Iowa to reduce expenses and travel costs. In the end, this resulted in the selection of four rural roundabouts one each outside New Prague, Minnesota and Paola, Florence and Garnett, Kansas as well as two rural two-way stop controlled intersections in Story County and Polk County, Iowa. Table 1 lists the intersection locations and characteristics.

**TABLE 1. Speed Data Collection Sites**

| State | Nearest City/Town | County | Intersection | Type | Legs | Posted Approach Speed Limit (Max) | Average Daily Entering Volume Before |
|---|---|---|---|---|---|---|---|
| Kansas | Florence | Marion | US 50/US 77 | Roundabout | 5 | 65 mph | 4,848 |
| Kansas | Garnett | Anderson | US 169/ K- 59 | Roundabout | 3 | 65 mph | 5,086 |
| Minnesota | New Prague | Scott | TH 13/CR 2 | Roundabout | 4 | 55 mph | 6,700 |
| Kansas | Paola | Miami | K-68/old Kansas City Rd/Hedge Lane | Roundabout | 5 | 65 mph | 6,260 |
| Iowa | Ames | Story | County Road R-38 and County Road E-36 | TWSC | 4 | 55 mph | 2,620 |
| Iowa | Alleman | Polk | State Highway 87 and County Road F22 | TWSC | 4 | 55 mph | 3,663 |

It was desirable to collect speed profiles on the approaches to the intersections in at least three locations, 100 ft, 250 ft and 500 ft in advance of the intersection and if possible also at two additional locations of 1,500 ft and 2,500 ft, as needed. The equipment considered for the collection of speed data were radar guns, Autoscope®, and TRAX® road tube data collectors. Each of these data collection equipment were available for this research; however the road tubes provided the most flexibility and efficient data collection for this number of locations on each approach with only one to two data collectors on hand.

A total of twelve road tube data recorders were available for use which dictated the number of approaches and number of locations where data could be collected at each intersection. For a statistically valid analysis of the speed data it was desirable to have at least 100 speed records at each road tube location for each approach, knowing that data could only be collected over a four to eight hour period with set up and tear down times needing to be removed from the data set.

Prior to finalizing the data collection layout and protocol a trial run was scheduled at the closest roundabout location, rural New Prague, MN. It was during this trail data collection effort that it was realized that six hours would be the maximum number of hours of data could be collected. This was due to the number of road tubes that had to be laid down per approach, one to two data collectors, the number of data recorders (twelve) available and the inability to leave the road tubes in place over night. Additionally, it was realized that one of the data recorders was not recording the data accurately which could have been a costly consequence if this had not been realized during this trail data collection effort. Before additional data were collected each data recorder was reset and recalibrated.

Data were collected in November and December 2007 (roundabouts) and September 2009 (two-way stop controlled) and avoided adverse weather and wet, snowy or icy road conditions. Once on site, the data collection team, observed the intersection and its environment and determined which approaches were best for data collection. Approaches with driveways or side roads that may impact the speed data collection were eliminated from consideration. In all, speed data were collected on ten approaches at four different roundabouts and seven approaches at two, two-way stop controlled intersections. Figure 3 shows an example of the road tube locations on one approach and Figure 4 shows the standard approach layout. Appendix H shows additional photos of road tubes at the various distances from the intersection. “Workers Ahead” warning signs were placed during the road tube installation and removal and permission to be in the right of way was obtained from each state Department of Transportation.

FIGURE 3. Road tube layouts at 250 ft and 100 ft from yield line in Minnesota

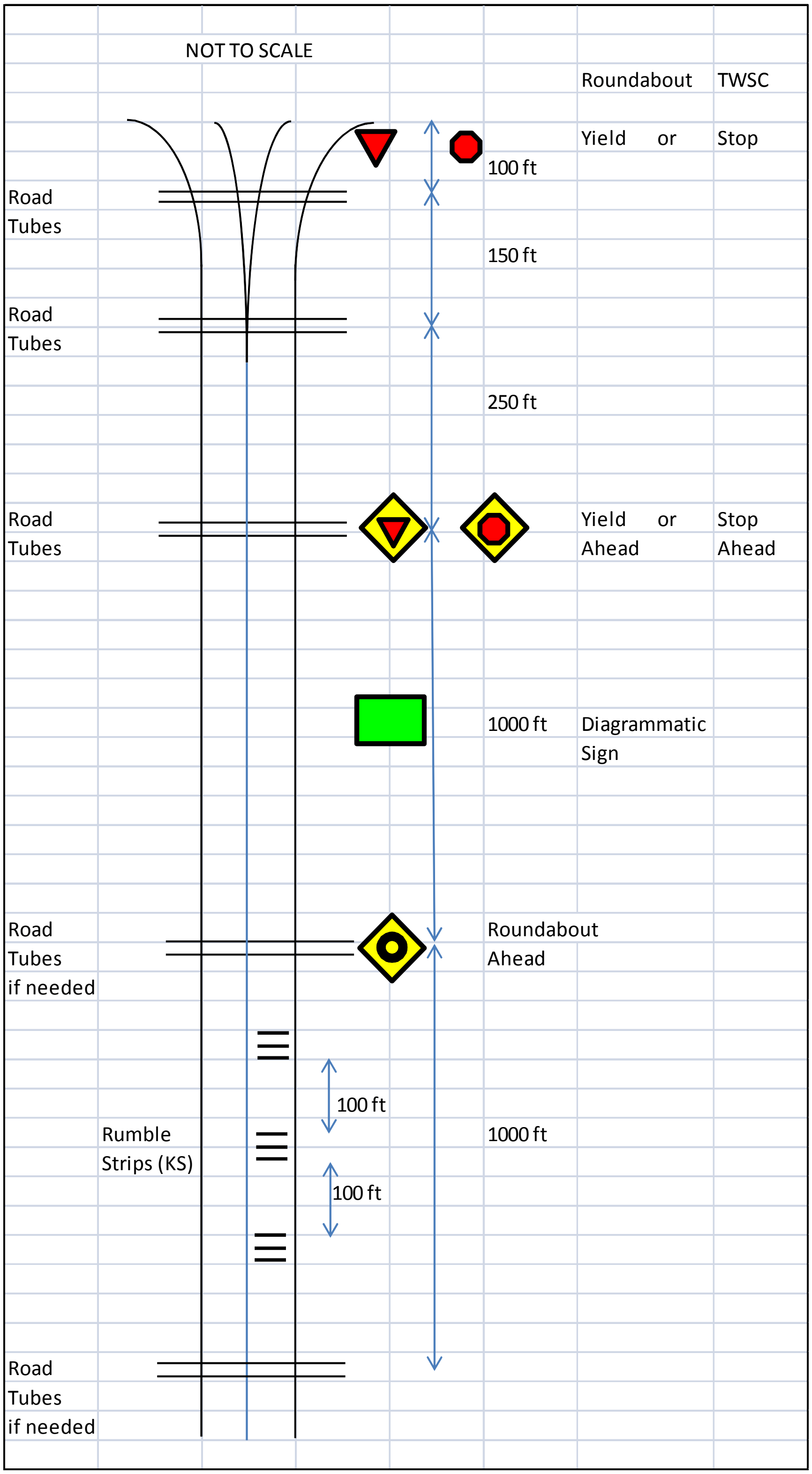

**FIGURE 4. Standard road tube layout**

The data collected at the two-way stop controlled intersections was done over a twenty-four hour period due to the lower volume roadways and their close proximity to the data collection team.

Data reduction was performed on all the speed data after exporting it with TRAX® software. All speed data that were collected during the road tube installation and removal timeframes were deleted from the data set, as well as all erroneous records (i.e. speeds equal to 0 mph, repeat records). Table 2 shows the number of speed data for each intersection. The speed profiles are shown in Appendix I.

**TABLE 2. Speed Data Records**

| **Intersection** | **Type** | **Number of Approaches Studied** | **Number of Speed Data** |
|---|---|---|---|
| New Prague, MN | Yield - Roundabout | 4 | 6,564 |
| Paola, KS | Yield  Roundabout | 3 | 6,436 |
| Florence, KS | Yield - Roundabout | 2 | 4,055 |
| Garnett, KS | Yield - Roundabout | 1 | 4,090 |
| Story County, IA | Stop Controlled - TWSC | 1 | 4, 211 |
| Polk County, IA | Stop Controlled - TWSC | 2 | 5, 315 |

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# CHAPTER 4. CRASH ANALYSIS OF ROUNDABOUTS AT HIGH-SPEED RURAL INTERSECTIONS

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Hillary N. Isebrands

## Abstract

Federal, state, and local agencies have identified increased intersection safety as an achievable objective in their campaigns for safer highways. Roundabouts have the potential to reduce the number of fatal and severe crashes. Roundabouts have been successful in Europe and Australia in both the urban and rural environments for decades. The documented safety benefits associated with roundabouts address numerous concerns surrounding injury crashes at intersections; however, applications of roundabouts on two-lane high-speed (40+ mph) rural highways have not been explored to the extent that urban roundabouts have in the United States. This research includes a safety analysis of roundabouts on high-speed rural roadways in the United States. The findings show the average injury crash frequency was reduced by 84%, average injury crash rate was reduced by 89%, angle crashes were reduced by 86%, and fatal crashes were reduced by 100%.

# Introduction

## Background

Intersections are a critical and necessary component in the roadway system; however, they are “a planned point of conflict” *(1)* which increases the likelihood for crashes. Intersection related fatalities typically account for approximately 21% of all roadway fatalities in the United States *(2).* Crashes at intersections account for nearly half of all fatal and injury crashes in the United States and over half of the fatal crashes occur in rural areas. These crashes are occurring on the over 3 million miles (75%) of designated rural highways across the United States each year *(3).*

Federal, state, and local agencies have identified increased intersection safety as an achievable objective in their campaigns for safer highways. In 2002, the Federal Highway Administration (FHWA) identified safety as one of the three “Vital Few” priority areas of the agency, along with environmental stewardship and streamlining, and congestion mitigation. Under this initiative, FHWA specifically set a goal of reducing intersection fatalities by 10% by 2007, or 921 fatalities per year. Over the past five years, the United States has fallen short of this 10% goal with an average reduction of 1.8%. However, in 2006 and 2007, a 4.5% and 6% reduction in fatalities were recorded, respectively. In addition, under the Highway Safety Improvement Program, FHWA has set aside $90 million per year until 2009 for the High Risk Rural Roads Program *(4).* The program’s focus is to significantly reduce fatalities and incapacitating injuries on rural major and minor collectors, and rural local roads.

Modern roundabouts, hereinafter referred to as roundabouts, are consistently gaining recognition as a safety alternative to traditional intersection design in the United States.

Roundabouts have the potential to reduce the number of fatal and severe crashes. Roundabouts have been successful in Europe and Australia in both the urban and rural environments for decades. The United Kingdom (U.K.) continues to replace many of its' traditional intersections with roundabouts and France builds approximately 1,000 new roundabouts per year *(5)*. It is estimated that there may be as many as 2,500 roundabouts in the United States but still less than 40 are on rural high-speed roadways similar to those found in this research.

## Need for Research

One viable alternative to safer intersections is the roundabout. The documented safety benefits associated with roundabouts address numerous concerns surrounding injury crashes at intersections; however, applications of roundabouts on two-lane high-speed (40+ mph) rural highways have not been explored to the extent that urban roundabouts have in the United States.

Despite the potential for roundabouts to reduce crash frequency and severity, apprehension still surrounds this high-speed treatment because of the reduction in approach speed needed to navigate the roundabout, driver unfamiliarity, unbalanced flows, and the ability to accommodate farm equipment and large semi trailers. There is a research need to substantiate the significant safety benefits. This paper addresses the safety benefits of rural roundabouts on high-speed roadways.

## Roundabouts on Rural High-speed Roadways

Transportation agencies are seeking new safety treatments for minimizing the number of crashes, and more specifically the number of both injury and fatal crashes. Rural areas, in particular, see a large proportion of fatal crashes based on average annual daily traffic (AADT). Roundabouts are one solution that is gaining attention across the United States as a viable intersection alternative that reduces injury crashes significantly.

### Rurality

The definition of rural means different things to different people, depending on what state the person is most familiar with. The United States Department of Agriculture has multiple definitions for a non-metro area with the most rural category defined as "completely rural or less than 2,500 urban population, not adjacent to a metro area" *(6).* Again, this does not provide clarity for defining rurality. Farmland, forestland, and prairieland can all be defined as rural, but a photo best describes the meaning of rural for this research. Figure 1 shows examples of rurality in the context of the intersections included in this analysis.

**FIGURE 1. Examples of roundabouts in rural settings (Image Sources: Isebrands, CH2MHill, Isebrands)**

## High-speed Roadways

Roundabouts on high-speed roadways are not “high-speed roundabouts.” Drivers at the intersections of high-speed roadways are navigating the roundabout at low speeds between 10 mph and 25mph. A common concern heard in the United States about roundabouts on high-speed roadways is how traffic will be able to reduce their speed from 45, 55, or 65 mph to navigate the roundabout at 15, 20, or 25 mph. Although modern roundabouts may be a “new” intersection design in the United States, our rural roadways have an abundance of situations where the driver must reduce their speeds after they have been driving at high speeds. It is common to see curve, turn, and chevron warning signs with advisory speed plates on rural roadways, as shown in Figure 2. Additionally, our rural roadways have traffic signals, stop signs, and flashing warning lights at intersections that require the driver’s attention and ability to slow the vehicle from high speeds to low speeds, or even come to a complete stop.

**FIGURE 2. Typical curve signing on rural roadways**

Slowing a vehicle from a cruising speed to a slower speed is not a foreign or problematic situation for most drivers; however, roundabouts are new to many drivers and unfamiliarity causes doubt. In this situation, it becomes very important that the transfer of knowledge from transportation professionals to the driving public be communicated, including the characteristics of roundabouts and their similarities and differences to traditional intersections.

## Education

Education of the public is critical to the success of any new type of intersection design, including roundabouts. Beginning educational efforts during the planning stages of a roundabout project by communicating the safety and operational benefits, and providing driving guidelines can prepare the public for an unfamiliar driving experience. It is also critical that the dissemination of project information continue with the public throughout the subsequent stages of the project, including design, construction, and immediately following the opening of the roundabout. An effective educational effort, coupled with sound geometric design, advance signing, and markings can ensure a successful driving experience.

## Literature

Although the number of roundabouts on high-speed roadways is relatively small, the safety benefits are evident. From Washington State, to Kansas, to Maryland, significant reductions in injury crashes are documented.

### *General Studies*

Safety benefits of roundabouts have been studied comprehensively in Europe and Australia. In Europe, “safety benefits seem to be greatest for single-lane roundabouts in rural conditions” *(7)*. This is likely attributed to the higher speeds at rural intersections, and the higher likelihood of reducing the severe crash history with the construction of a roundabout.

With a limited number of roundabouts in the United States to perform extensive safety analysis, similarities in accident prediction models from the U.K. and the United States for conventional intersections may allow the United States to conclude that roundabouts have the potential to reduce crashes in the United States, as they do in the U.K. *(8).*

Persaud et al. *(4)* conducted an empirical Bayes observational before and after study on 23 intersections in the United States that resulted in a 40% reduction in all crashes, and an 80% reduction in injury crashes. The single-lane rural intersections included in this study resulted in a 58% and an 82% reduction, for total and injury crashes, respectively.

Maryland has approximately 13 roundabouts on high-speed roadways with many of them being constructed in the mid 1990's. Based on the data in a study done by the Maryland State Highway Administration *(9)*, ten of those roundabouts show an average reduction in injury crashes of 79%. These before and after descriptive statistics are for an average of 4.5 years before and 8 years after, which minimizes the potential for regression to the mean.

A 3-year study by Flannery *(10)* looked at the effect of geometric design on safety performance at eight single lane roundabouts. Approximately 45% of the crashes were loss-of-control and almost all were at high-speed rural locations. The research concluded that the straight approaches and the geometry of the roundabout (entry deflection, entry radius, and inscribed circle diameter) were not sufficient at these locations.

### *Project Related Studies*

Washington State Department of Transportation (WSDOT) considered a roundabout as an intersection reconstruction alternative for a high-speed rural intersection in King

County. Concerns were raised about the safety of roundabouts on high-speed roadways *(11)*. WSDOT designers compared crash rates at U.K. roundabouts verses high-speed signalized intersections, in King County, at rural intersections with roadway speeds over 45 mph. They reported the following information, as shown in Table 1. The crash statistics for the rural roundabouts (50 - 70mph) were taken from a safety study of over 80 roundabouts in the U.K. *(12)*. WSDOT used this crash research to assist in selecting a design alternative for the Novelty Hill Road project. A high-speed rural roundabout was constructed in 2004.

**TABLE 1. Injury Accident Statistics –Roundabouts vs. Signals on High-speed Roadways *(13)***

| Category | **Injury Accidents per 100 Million Vehicles** | | | | | |
|---|---|---|---|---|---|---|
| | Fatal | Serious | Slight | Total | Number of Sites | Average Daily Traffic |
| **Roundabouts 50–70 mph**[1] | 0.19 | 3.8 | 24.7 | 28.7 | 11 | 27,800 |
| **Signals 45-55 mph**[2] | 0.56 | 11.8 | 39.2 | 51.5 | 8 | 20,400 |
| **Novelty Hill Road, Existing**[2] | 0.0 | 29.9 | 62.3 | 92.2 | 1 | 13,700 |
| **Projected Roundabout**[3] | 0.13 | 2.54 | 16.52 | 19.19 | | |

1 LR1120 “Accidents at 4-arm Roundabouts”

2 WSDOT Accident Records and WSDOT Traffic Counts

3 Projections from RODEL Ltd.

Rosales et al. *(14)*, performed an alternative study for two intersections along a corridor in Washington County, OR, where there was a high number of crashes over a five-year period. The intersection alternative needed to improve safety (i.e. reduce crashes), provide room for large trucks and agricultural equipment, and minimize the environmental impacts (wetlands, farm land). Two roundabout and two traditional intersection alternatives were analyzed. A project advisory committee was established to recommend the best alternative based the criteria above. Roundabout alternatives were chosen for both intersections based on safety and the ability of the roundabout to improve intersection operations and provide priority given to major traffic movement.

A 2005 study for the California Department of Transportation evaluated the perceived concern of roundabouts at high-speed roadways through five case studies of roundabouts in the United States and Canada. The report concluded that there is not statistically sufficient evidence of a correlation between geometric design of high-speed approaches and the intersection safety performance in North America. This study also found that positive safety performance is typically attributed to visible entries, reduced entry speeds, extension of the splitter island to the deceleration length, and landscaped center islands that prevent "see through" *(15).*

## Before and After Analysis

### Data Collection

Seventeen intersections on high-speed roadways that were converted to roundabouts were evaluated in this analysis. Before and after crash records were solicited from each agency with jurisdiction over the roundabout. Table 2 shows the intersections that were included in this analysis.  Thirteen of the intersections had four approach legs and approach speeds ranged from 40 mph to 65 mph.

The exposure data was also obtained from the agencies and included either AADT for the intersection or average daily traffic (ADT) for the approaches.  The daily entering vehicles (DEV) was calculated as ADT/2.  The DEV was consistent among 16 of the intersections with an average minimum count of 3,015 and an average maximum count of 6,728 over an average 5 year before period.  One intersection had a DEV of approximately 16,000.

The number of years of before data averaged 4.6 years with a minimum of 2.5 years and a maximum of 6.6 years.  The after data varied more than the before data with an average of 5.5 years with a minimum of 1.8 years and a maximum of 12.7 years of data.

## Crash Frequency

Collectively at the seventeen intersections, 414 total crashes and 264 injury crashes were reported prior to the roundabout construction over an average of a 4.6 year period. After the roundabouts were constructed, 200 total crashes and 41 injury crashes were reported over the average of a 5.5 year period.  Figure 3 shows the number of crashes by intersection.  Only two intersections had an increase in the total number of crashes; in contrast, both of these intersections experienced a 67% and 60% reduction in injury crashes. (Note: the lines shown in the Figures 3 and 4 do not indicate a relationship between the points, but are used to more clearly show the crash trends before and after the installation of roundabouts), the average total crash frequency was reduced by 52% and the average injury crash frequency was reduced by 84%.

Not only did the total crashes decrease, but the number of injury crashes were also reduced and at a higher rate than the total number of crashes. The ratio of injury crashes to total crashes dropped dramatically, from 60% to 20% which is 66% reduction.

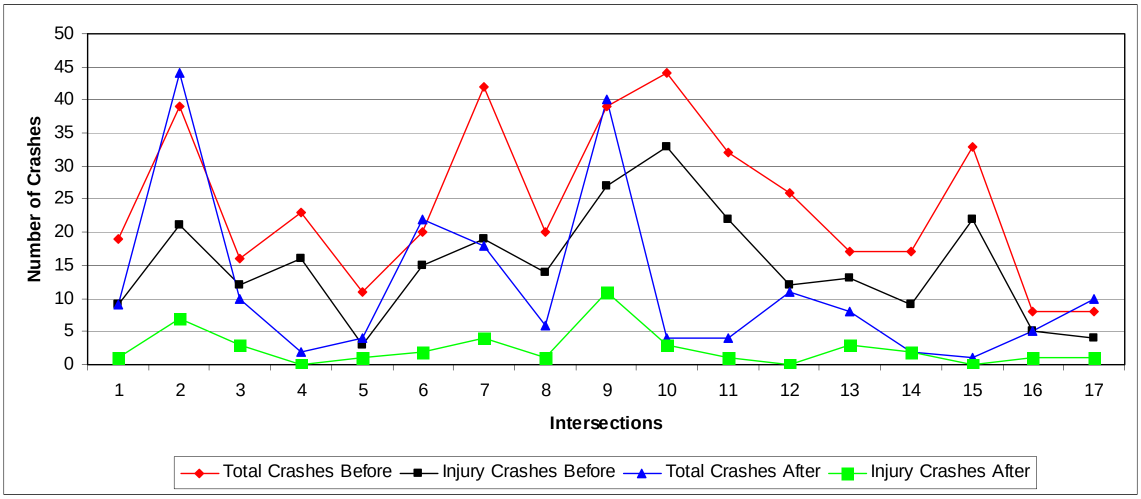

**FIGURE 3. Crash frequency by intersection**

## Crash Rate

Crashes per million entering vehicles (MEV) were evaluated to account for the traffic exposure at the intersections. Figure 4 shows the crash rates per MEV by intersection. Only one intersection showed an increase in the total crash rate. This intersection had approximately 5 years of before crash data and 4 years of after crash data. Three intersections reported no injury crashes once the roundabouts were constructed. The average intersection crash rate was reduced by 67% and the average injury crash rate was reduced by 89%.

**TABLE 2. Study Intersection Locations**

| | State | City/Town | County | Intersection | Installation year | Legs | Posted Approach Speed Limit (Max) |
|---|---|---|---|---|---|---|---|
| 1 | Maryland[1] | Cearfoss/Hagerstown | Washington | MD 63/MD58/Cearfoss Pike | 1995 | 4 | 50 mph |
| 2 | Washington[2] | Duvall | King | SR 203/Novelty Hill Rd | 2004 | 4 | 50 mph |
| 3 | Maryland[1] | Federalsburg | Caroline | MD 307/MD 313/MD 318 | 1998 | 4 | 50 mph |
| 4 | Kansas[3] | Florence | Marion | US 50/US 77 | 2006 | 5 | 65 mph |
| 5 | Kansas[3] | Garnett | Anderson | US 169/ K- 59 | 2006 | 3 | 65 mph |
| 6 | Maryland[1] | Leeds | Cecil | MD 213/Leeds Rd/Elk Mills Rd | 1995 | 4 | 40 mph |
| 7 | Maryland[1] | Lisbon | Howard | MD 94/MD 144 | 1993 | 4 | 45 mph |
| 8 | Maryland[1] | Lisbon | Howard | MD 94/Old Fredrick Road | 1998 | 4 | 45 mph |
| 9 | Maryland[1] | Lothian | Anne Arundel | MD 2/MD 408/MD 422 | 1995 | 4 | 50 mph |
| 10 | Minnesota[4] | New Prague | Scott | TH 13/CR 2 | 2005 | 4 | 55 mph |
| 11 | Maryland[1] | North Harford/Jarretsville | Harford | MD24/MD165 | 2000 | 4 | 55 mph |
| 12 | Kansas[3] | Paola | Miami | K-68/old Kansas City Rd/Hedge Lane | 2001 | 5 | 65 mph |
| 13 | Maryland[1] | Rising Sun | Cecil | MD 273/MD 276 | 2002 | 4 | 45 mph |
| 14 | Maryland[1] | Rosemont | Frederick | MD 17/MD 180 | 2000 | 4 | 50 mph |
| 15 | Washington[2] | Spokane | Spokane | SR 206/ Bruce Rd | 2005 | 4 | 50 mph |
| 16 | Oregon[5] | Verboort | Washington | Verboort Rd/Martin/Marsh | 2004 | 4 | 45 mph |
| 17 | Oregon[5] | Verboort | Washington | Verboort Rd/Corneilius Schefflin | 2004 | 3 | 45 mph |

[1] Maryland State Highway Administration, Office of Traffic and Safety, 2007 [9]

[2] Washington DOT, 2008 [16]

[3] Kansas Department of Transportation, Office of Chief Counsel, 2008 [17]

[4] Minnesota Department of Transportation, Office of Traffic and Safety, 2008 [18]

[5] Washington County, Oregon, 2008 [19]

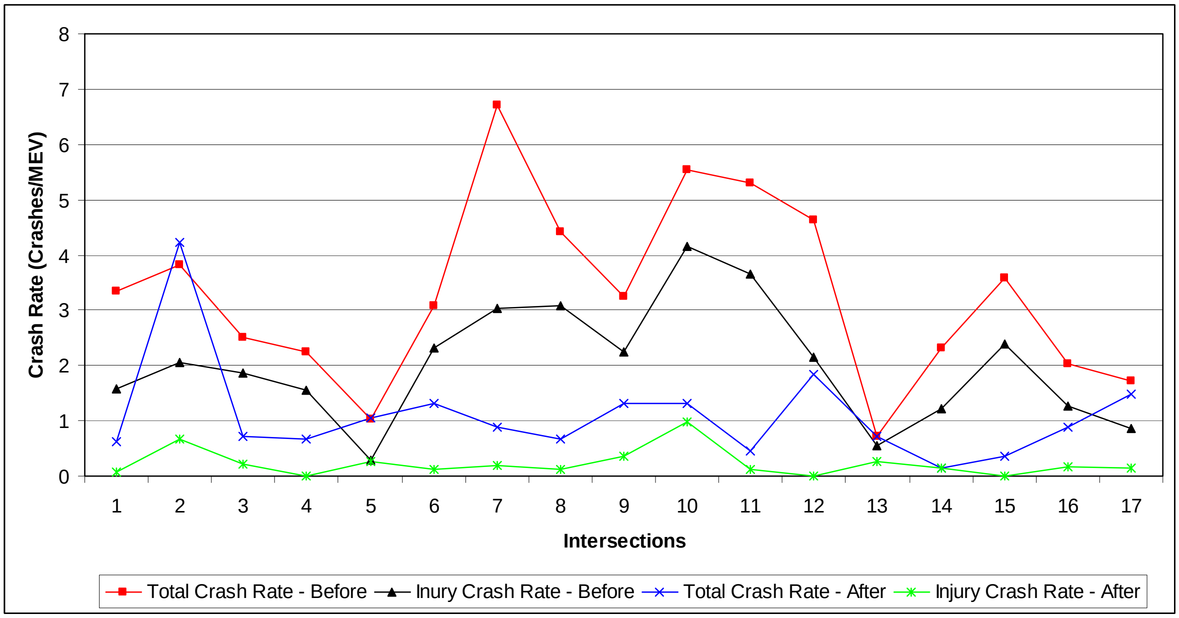

**FIGURE 4. Crash rate by intersection**

## Crash Severity

When only considering the change in the total number of crashes, it does not distinguish between property damage only (PDO) crashes, which tend to be minor, and the various types of injury crashes. The efforts and benefits in reducing crashes are more significant when injury crashes can be reduced, as was the case with all of the roundabouts in this study. Table 3 and Figure 5 show the percent reductions and number of crashes in the before and after periods.

**TABLE 3. Reduction in Crash Severity**

| Crash Severity | Reduction |
|---|---|
| **Fatal** | 100% |
| **Injury** | 82% |
| **General**[1] | 86% |
| **Incapacitating/Serious** | 89% |
| **Non-incapacitating/Evident** | 83% |
| **Property Damage Only** | No change |

[1] Indicates that type of injury was not specified (12 intersections)

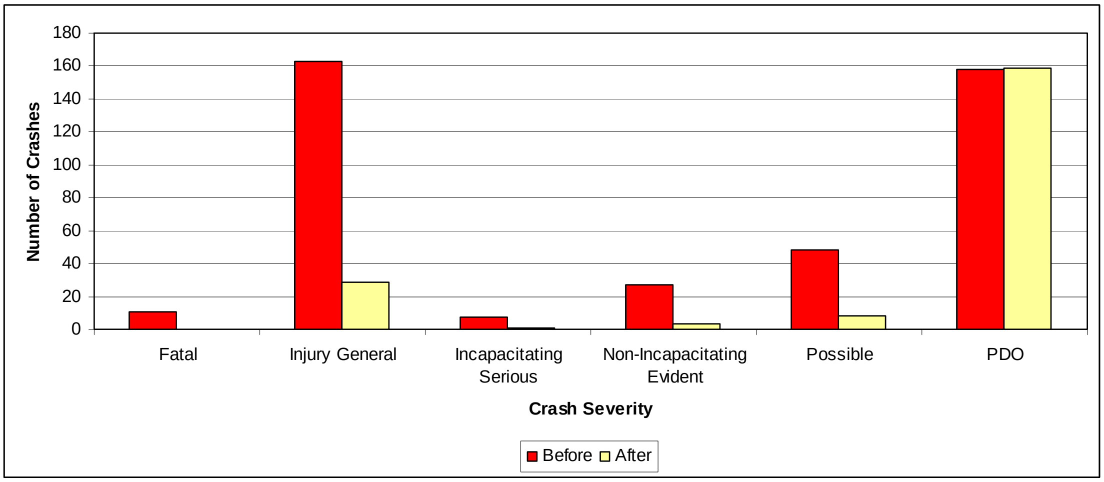

**FIGURE 5. Crash severity**

## Crash Types

The very nature of a roundabout intersection changes the types of crashes that occur at the intersection. Typically, certain intersection crash types are associated with more severe injuries, such as angle and turning crashes, whereas rear end and side swipe crashes tend to cause less severe crashes. Figure 6 shows two single vehicle crashes at roundabouts.

For the study intersections, angle crashes were the most dominant type of crash. Angle crashes were reduced by 86%. Fixed object crashes increased by 320%; sideswipe crashes, which are more likely at roundabouts, increased by 140%; and rear end crashes decreased by 19%. Figure 7 illustrates the differences in the number of crashes for each type.

**FIGURE 6. Left – Single vehicle crash in Washington (Image Source: Washington DOT); Right - Truck rollover crash in Kansas (Image Source: © Marion County Record)**

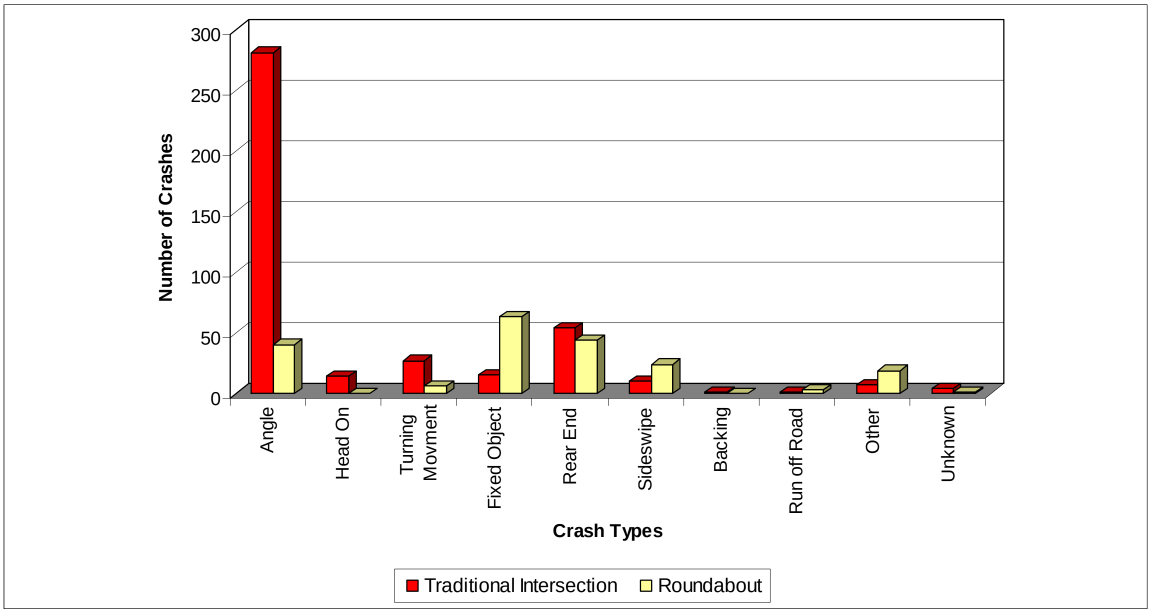

**FIGURE 7. Intersection crash types before and after roundabout**

## Summary

Transportation agencies are still in search of solutions that will improve safety, and more specifically reduce the number of injury crashes and their severity. Rural roundabouts provide an effective resolution to an intersection with a poor crash history, and more importantly, an intersection with a history of severe crashes. Furthermore, roundabouts have the potential to prevent similar crashes from occurring at new intersections on rural roadways. Several states have embraced the safety benefits that rural roundabouts provide and these states are continuing to construct roundabouts on high-speed roadways.

The results of this analysis show a 52% and a 67% reduction in total crashes and crash rate, respectively. Moreover, the findings showed an 84% reduction in injury crashes and an 89% reduction in the injury crash rate. No fatal crashes have occurred since the roundabouts were constructed, whereas 11 fatal crashes were reported in the before period. The number of angle crashes were also reduced by 86%.

The next step in this research is to conduct a statistical significance test for the measures of effectiveness to determine if the reductions are significant statistically. Regardless, it is evident that these results demonstrate to the effectiveness of roundabouts in reducing the number of injury crashes at rural intersections on high-speed roadways.

## Acknowledgements

Without the scholarships from the FHWA Dwight D. Eisenhower Graduate Programs Fellowship Program and the Midwest Transportation Consortium and Iowa State University, Center for Transportation Research and Education this research would not have been possible.

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# CHAPTER 5. A STATISTICAL ANALYSIS AND DEVELOPMENT OF A CRASH PREDICTION MODEL FOR ROUNDABOUTS ON HIGH-SPEED RURAL ROADWAYS

A paper submitted to the *Transportation Research Record, Journal of the Transportation Research Board.*

Hillary Isebrands and Shauna Hallmark

## Abstract

Roundabouts have proven to be effective in urban and suburban environments in the United States, but little has been reported on their effectiveness in rural environments with high-speed roadways. There is no question that roundabouts reduce speeds of all vehicles at intersections and reduce the frequency of fatal and injury related crashes.

This research is the first comprehensive look at roundabouts in a rural environment with high speed approaches. Nineteen intersections had ample comprehensive crash data to be evaluated and analyzed for safety performance. The findings validated the hypothesis that roundabouts in a rural environment out perform other intersection safety improvements as well as roundabouts in urban and suburban environments. A before and after crash analysis was conducted for the nineteen intersections using a negative binomial regression model . Results showed statistically significant reductions for both the total number of crashes (63%) and injury crashes (88%) when roundabouts were implemented. A before and after empirical Bayes estimation was also conducted and the results were consistent, indicating a 62 to 67% reduction in total crashes and an 85 to 87% reduction in injury crashes at these rural

intersections. Furthermore, results showed that injury producing crash types, such as the angle crash, were reduced by 91%, and were statistically significant.

Finally, this research produced planning level crash prediction models for both total and injury crashes at rural roundabouts on high-speed roadways which supplement the models produced in NCHRP Report 572 Roundabouts in the United States and will be considered for inclusion in the next edition of the AASHTO Highway Safety Manual.

## Introduction

Historically, intersection related fatalities account for approximately 21% of all roadway fatalities in the United States and 40% of those fatal crashes occur in rural locations *(1)*. The Federal Highway Administration (FHWA) continues to strive to make improvements in intersection safety *(2)*. Under the Highway Safety Improvement Program, FHWA set aside

$90 million per year until 2009 for the High Risk Rural Roads Program. The program's focus is to significantly reduce fatalities and incapacitating injuries on rural major and minor collectors, and rural local roads. Rural areas, in particular, see a large proportion of fatal crashes based on average annual daily traffic (AADT).

Modern roundabouts are gaining attention across the United States as a viable intersection alternative that reduces injury crashes significantly. Modern roundabouts hereinafter referred to as roundabouts, have been successful in Europe and Australia in both the urban and rural environments for decades. The United Kingdom (U.K.) continues to replace many of its' traditional intersections with roundabouts and France builds approximately 1,000 new roundabouts per year *(3)*. It is estimated that there are nearly 3,000 roundabouts already in the United States but less than 50 are on rural roadways.

The documented safety benefits associated with roundabouts address numerous concerns surrounding injury crashes at intersections; however, applications of roundabouts on two-lane high-speed (40+ mph) rural highways have not been explored to the extent that urban roundabouts have in the United States. Some skepticism arises from the awareness that rural driving environment takes on a different set of expectations. Often there are few vehicles on the road, street lighting is sparse and intersections are few and far between. Thomas and Nicholson *(4)* disclose that the rural environment can even induce a lower level of alertness with the decreased level of demand on the driver.

Roundabouts on high-speed roadways are not “high-speed roundabouts.” Drivers at the intersections of high-speed roadways are navigating the roundabout at low speeds, between 10 mph and 25mph which are similar to speeds at roundabouts in urban areas. Well designed roundabouts produce low absolute speeds (15 to 25 mph) for all drivers allowing them to react to potential crashes *(4)*. Roundabouts have been proven *(5,6,7)* to reduce the number of injury crashes at intersections, albeit a reduction in the total number of crashes is not always experienced, particularly at multi-lane roundabouts. Ultimately, there is a reduced probability of being involved in a high-speed, injury crash at a well-designed roundabout.

So the question remains, how can roundabouts, in a rural environment where there may already be an apathetic driving attitude due to longer distances between developed areas improve the intersection safety experience? The objectives of this research were to provide quantitative evidence of rural roundabout crash data enhanced with statistical analyses that assesses the safety and effectiveness of roundabouts at rural locations with high-speed approaches. A secondary objective was to develop of crash prediction model specifically for rural roundabouts on high-speed roadways.

## Background

The literature specifically pertaining to roundabout in rural locations and/or with high-speed approaches was sparse; however several larger studies have included minimal rural roundabout and/or roundabouts with high-speed approaches.

### International

One of the most referred to roundabout safety studies around is a study done by Maycock and Hall *(8)* in the United Kingdom. They performed an analysis of accidents at four-arm roundabouts. Eighty-four roundabouts were included in the research with 11 sites that would be considered on high-speed roadways (with similar design characteristics to roundabouts in the United States.) Over the 53 intersection crash years, these 11 roundabouts experienced 1-fatal, 20-serious and 129-slight injury crashes which equates to 2.83 crashes per intersection per year. The experience at these 11 roundabouts was slightly lower than the overall average of 3.31 injury crashes per intersection per year. More recently in the United Kingdom, Kennedy et al. *(9)* conducted a crash study on 1,162 roundabouts and found the average injury crash frequency to be 1.77 injury crashes per intersection per year. Additionally, the research found that single-lane roundabouts for both three-arm and four-arm roundabouts have a lower injury crash frequency.

In New Zealand, Thomas and Nicholson *(4)* discussed many of the design features of rural roundabouts that are essential to maintaining a high level of safety:

1.) Geometric design should minimize the relative speeds between vehicles, as many rural roundabouts can potentially have a higher number of large trucks.

2.) Low absolute speeds for all drivers allowing them to react to potential crashes.

3.) Adequate deflection to keep speeds low and conflicting speeds consistent.

4.) Appropriate approach, entering and intersection sight distances.

5.) Avoid inducing curvature (reverse curves) on the approaches

6.) Splitter islands should be at least 60m (200 ft) in length but desirable to have it the length of the deceleration distance on the approach to the roundabout.

7.) Lighting is required but the lighting configuration should not be misleading.

8.) Installation of transverse pavement markings to induce speed reduction on the approaches, where necessary.

9.) Driver education.

The study also reported crash frequency data for four rural roundabouts near Christchurch and Rotura. Overall, the percent reduction in injury crashes ranged from 86% to 100% for the rural roundabouts.

## United States

In 2001, Persaud et al. *(6)* conducted an empirical Bayes observational before-after study on 23 intersections in the United States that resulted in a 40% reduction in all crashes and an

80% reduction in injury crashes.  Five rural, single-lane roundabouts experienced a 58% reduction in total crashes and an 82% reduction in injury crashes.  Even though the number of rural roundabout was small it was the first indication that roundabouts being placed in urban, suburban and rural locations have a similar safety impact.

The most comprehensive safety study on roundabouts in the United States was published in NCHRP Report 572 *(7)*.  Nine of the 55 intersection included in the study were considered rural intersections.  All nine roundabouts were single-lane roundabouts.  The results of the empirical Bayes before and after study indicated that these nine intersections showed an estimate of the percentage reduction in crashes to be 72% for total crashes and 87% for injury crashes.  This compares favorably to the overall percentages for all the intersections, where the reduction for total and injury crashes was 35% and 76%, respectively.  The US safety data on roundabouts is consistent with the experiences abroad.

Mandivilli et al. *(10)* reported on the general crash characteristics of 29 single-lane roundabouts and nine two-lane roundabouts in Maryland constructed from 1993 to 2005. Several of the roundabouts included in this study were rural roundabouts on high-speed roadways.  Run-off-road, rear end, entering-circulating and sideswipe crashes accounted for 97% of the 149 total crashes.  Of those, 50% were single vehicle run-off-road and “unsafe” speeds were reported at 50% of those crashes.  Rear end crashes accounted for 34% of the crashes and entering-circulating (i.e. failure to yield) crashes accounted for 13%.  Field observations suggested that speed related issues may have resulted from lack of advanced signing, insufficient street lighting, wide approach lane widths, lack of conspicuous central island landscaping, and short splitter island lengths.  The authors suggest several low costs solutions to encourage speed reduction prior to the roundabout, some include enhanced landscaping, reflective signs on the central island, extension of the splitter island, and enhanced street lighting.

## Intersection Data

This research builds on existing, smaller data sets that have included rural roundabouts *(6,7)*. Each of the intersections had to meet several criteria to be included in the data set of rural roundabouts on high-speed roadways. One, the intersection had to be rural in nature and two; the intersection had to have at least one high-speed roadway. The true definition of rural, for this research, relies on a combination of a formal definition and a qualitative assessment of the intersection environment. A formal definition, as sited by the United States Department of Agriculture *(11)* is an area that is “completely rural or less than 2,500 urban population, not adjacent to a metro area.” The AASHTO Highway Safety Manual *(12)* sites a rural area with a population of less than 5,000. A more qualitative definition, describes an area surrounded by farmland, forestland, prairieland, or grassland or combination thereof and roads leading up to the intersections are often isolated with high speeds, over 40mph.

The data base of intersections includes 20 rural intersections which were converted to roundabouts in six US states (Maryland, Kansas, Wisconsin, Washington, Oregon, Minnesota) and Ontario, Canada. Nine of these intersections (eight from Maryland) have been included in other before-after studies *(6,7)*, however this new data set builds on the past analyses with more than double the number of intersections and number of years of data, both before and after the roundabout installations. Table 1 provides a summary of each of the intersections.

**TABLE 1. Intersection Locations and Characteristics**

| | State | City/Town | County | Intersection | Roundabout installation year | Legs | Posted Approach Speed Limit (Max) |
|---|---|---|---|---|---|---|---|
| 1 | Maryland[1] | Cearfoss/Hagerstown | Washington | MD 63/MD58/Cearfoss Pike | 1995 | 4 | 50 mph |
| 2 | Washington[2] | Duvall | King | SR 203/Novelty Hill Rd | 2004 | 4 | 50 mph |
| 3 | Maryland[1] | Federalsburg | Caroline | MD 307/MD 313/MD 318 | 1998 | 4 | 50 mph |
| 4 | Kansas[3] | Florence | Marion | US 50/US 77 | 2006 | 5 | 65 mph |
| 5 | Kansas[3] | Garnett | Anderson | US 169/ K- 59 | 2006 | 3 | 65 mph |
| 6 | Wisconsin[6] | Kaukauna | Outagamie | STH 55/CTH KK | 2006 | 4 | 55 mph |
| 7 | Maryland[1] | Leeds | Cecil | MD 213/Leeds Rd/Elk Mills Rd | 1995 | 4 | 40 mph |
| 8 | Maryland[1] | Lisbon | Howard | MD 94/MD 144 | 1993 | 4 | 45 mph |
| 9 | Maryland[1] | Lisbon | Howard | MD 94/Old Fredrick Road | 1998 | 4 | 45 mph |
| 10 | Maryland[1] | Lothian | Anne Arundel | MD 2/MD 408/MD 422 | 1995 | 4 | 50 mph |
| 11 | Minnesota[4] | New Prague | Scott | TH 13/CR 2 | 2005 | 4 | 55 mph |
| 12 | Maryland[1] | North Harford/Jarretsville | Harford | MD24/MD165 | 2000 | 4 | 55 mph |
| 13 | Kansas[3] | Paola | Miami | K-68/old Kansas City Rd/Hedge Lane | 2001 | 5 | 65 mph |
| 14 | Maryland[1] | Rising Sun | Cecil | MD 273/MD 276 | 2002 | 4 | 45 mph |
| 15 | Maryland[1] | Rosemont | Frederick | MD 17/MD 180 | 2000 | 4 | 50 mph |
| 16 | Wisconsin[6] | Sheboygan Falls | Sheboygan | STH 32/STH 28 | 2006 | 4 | 55 mph |
| 17 | Washington[2] | Spokane | Spokane | SR 206/ Bruce Rd | 2005 | 4 | 50 mph |
| 18 | Oregon[5] | Verboort | Washington | Verboort Rd/Martin/Marsh | 2004 | 4 | 45 mph |
| 19 | Oregon[5] | Verboort | Washington | Verboort Rd/Corneilius Schefflin | 2004 | 3 | 45 mph |
| 20 | Ontario[7] | St. Jacobs | Waterloo | Arthur/Sawmill | 2006 | 4 | 55 mph |

[1] Maryland State Highway Administration, Office of Traffic and Safety, 2007 [7]
[2] Washington DOT, 2008 [15]
[3] Kansas Department of Transportation, Office of Chief Counsel, 2008 [16]
[4] Minnesota Department of Transportation, Office of Traffic and Safety, 2008 [17]
[5] Washington County, Oregon, 2008 [18]
[6] Wisconsin Department of Tranportation, 2008
[7] Region of Waterloo, Ontario, Canada, 2008

Prior to being converted to a roundabout, one intersection had signal control, two were three-legged intersections with one-way stop controlled and the remaining were two-way stop controlled intersections.  Over half of the stopped controlled intersections had intersection control beacons, yellow flashing on the major route and red flashing on the minor route.  According to the MUTCD *(13)*, intersection control beacons may be used to provide adequate visibility or where crash rates indicate a need and a conventional traffic signal control is not warranted.

Although the intersection in St. Jacobs, Ontario meets the criteria as rural roundabout with high-speed approaches, several characteristics set it apart from the other 19 intersections and it was removed from the data set for the analysis and crash prediction model development (i.e. signalized in the before condition, higher traffic volume, decrease in traffic volume in the after condition).The following list highlights those differences:

- Before traffic volumes were over double that of the other intersections
- After traffic volumes decreased by 20%
- Total crashes per year increased by 200% (Injury crashes per year decreased by 25%)
- Two circulating lanes within the roundabout (19 sideswipe crashes)
- Before traffic control was a signal
- 2 years of after crash data

Because of these anomalies, this intersection was removed from the data set.

Major and minor road traffic volumes were all obtained from the jurisdictions in the form of AADT (Annual Average Daily Traffic) or intersection traffic counts converted to AADT. The daily entering vehicles (DEV) was calculated as AADT/2 if it was not provided specifically by direction and approach. The mean DEV for the major and minor roads were approximately 7,000 and 2,800, respectively. The number of years of before and after data averaged 5.2 years. The average increase in volumes from the before to after period was 15%. Table 2 provides a summary of the traffic volumes and crashes.

Crash and intersection data were obtained from the respective jurisdictions, NCHRP Report 572, and field observations (15 intersections). Though, it was inevitable that crash data from seven different jurisdictions would not result in identical reporting methods, careful consideration was made when extracting the crash data from these sources and comparing them to one another. Either crash record summaries/crash diagrams with officer comments were available from all the jurisdictions or preferably data extracted from police reports was used, when available. In some cases, crash reports were not available for both the before and after periods, only summary data. The total number of crashes that occurred at these intersections in the before and after periods were 504 and 298, respectively. Before and after records indicated that injury crashes, including fatal and possible injury, were 211 and 43, respectively.

**TABLE 2. Intersection Data (19 Intersections)[1]**

| | **Minimum** | | **Maximum** | | **Mean** | | **Std. Dev** | |
|---|---|---|---|---|---|---|---|---|
| | Before | After | Before | After | Before | After | Before | After |
| **Major Road DEV** | 3,181 | 3,160 | 12,317 | 13,775 | 6,368 | 7,327 | 2,721 | 3,180 |
| **Minor Road DEV** | 1,150 | 1,377 | 6,042 | 5,656 | 2,624 | 2,969 | 1,124 | 1,061 |
| **Total Crashes** | 8 | 1 | 44 | 48 | 27 | 11 | 13 | 13 |
| **Injury Crashes** | 3 | 0 | 33 | 11 | 16 | 2 | 8 | 3 |
| **Years** | 2.5 | 1.67 | 8.75 | 12.7 | 5.2 | 5.2 | 1.7 | 3.5 |

## Descriptive/Summary Statistics

Although descriptive statistics do not account for the variance between the number of before and after years and changes in traffic volumes, they are able to provide a snapshot of the intersections, crash experience and changes in crash experience after a safety countermeasure, a roundabout in this case, is applied.

For the 19 intersections, 511 total crashes and 299 injury crashes were reported during the before period. This includes 98 data years before and after for the intersections. There was a 59% reduction in total crashes and 85% reduction in injury crashes (After - 212 Total and 44 Injury crashes). Table 3 summarizes the descriptive statistics for the dataset. Only one intersection had an increase in the total number of crashes/year. All intersections showed a decrease in the injury crashes from 3.8/year to 1.9/year. The ratio of injury crashes to total crashes decreased from 59% to 21% in the after period. Total crash rates and injury crash rates decreased by 64% and 87%, respectively, while the average traffic volumes increased by 9%.

**TABLE 3. Change in Crash Data Before and After Roundabout - Descriptive**

| Measure of Effectiveness | Before | After | Percent Change |
|---|---|---|---|
| **Total crashes** | 511 | 212 | -0.59 |
| **Injury crashes** | 299 | 44 | -0.85 |
| **Years of data** | 98.2 | 98.2 | No change |
| **Mean total crashes/year** | 5.11 | 2.38 | -0.53 |
| **Mean injury crashes/year** | 3.02 | 0.53 | -0.83 |
| **Mean crashes/intersection** | 26.9 | 11.15 | -0.59 |
| **Average injury crashes/intersection** | 15.74 | 2.32 | -0.85 |
| **Mean crashes/MEV** | 1.68 | 0.61 | -0.64 |
| **Injury crashes/MEV** | 0.97 | 0.13 | -0.87 |

Crash severity shows similar trends. The benefits of reducing injury crashes are more significant than considering overall reduction in crashes *(14)*. Table 4 shows the reductions in injury crashes after roundabouts and Figure 1 illustrates the breakdown of all crashes.

**TABLE 4. Reduction in Crash Severity**

| | Before | After | Percent Change |
|---|---|---|---|
| **Injury - total** | 299 | 44 | -85% |
| **Fatal** | 12[1] | 0 | -100% |
| **General**[1] | 98 | 9 | -91% |
| **Incapacitating/Serious** | 46 | 6 | -87% |
| **Non-incapacitating/ Evident** | 59 | 13 | -78% |
| **Possible Injury** | 84 | 16 | -81% |
| **Property damage only** | 212 | 168 | -21% |
| [1] Eight intersections had fatal crashes. | | | |

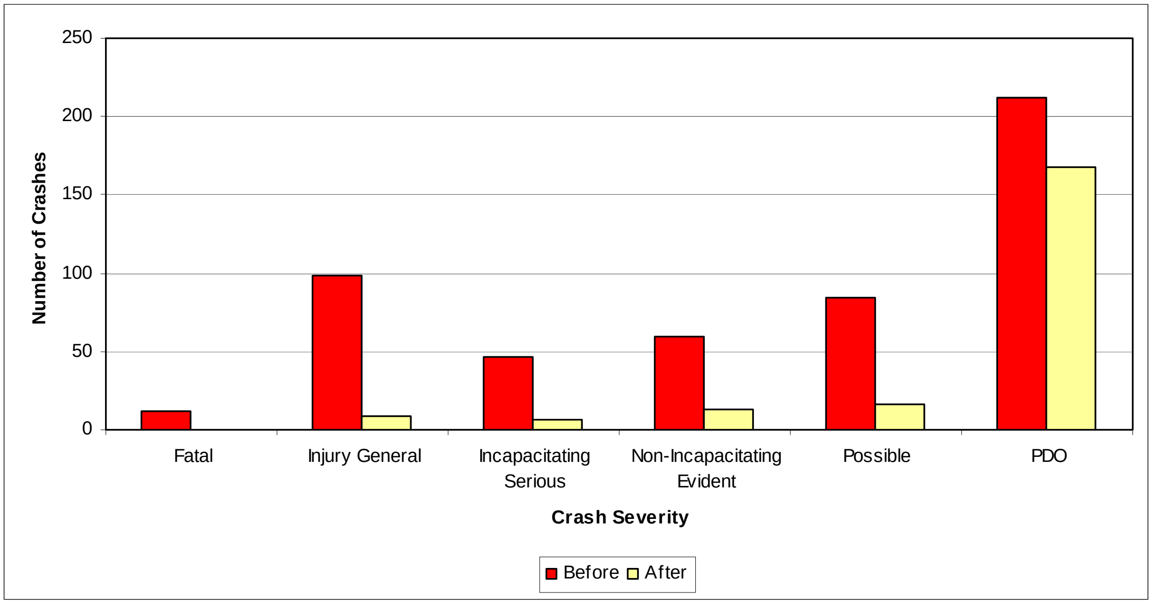

**FIGURE 1. Crash severity**

The very nature of a roundabout intersection changes the types of crashes that occur at the intersection *(14)*. While roundabouts tend to decrease the number of angle and turning crashes, they do have the potential to increase sideswipe and rear end crashes *(5,7)*. Mandivilli *(10)* found that rear-end; run-off-road and sideswipe crashes can increase at some roundabouts. Angle crashes are potentially the most dangerous type of crash, especially when the speed differential between the vehicles is substantial, for example when one vehicle is at free-flow speed (40 – 65 mph) and the other vehicle is starting from a stop condition. An intersection crash resulting from such a situation is shown in Figure 2.

**FIGURE 2. Implications of an angle crash at an intersection (Photo Source: FHWA)**

In the case of these rural intersections, angle and turning crashes make up 74% of all the crashes in the before period. These crashes were reduced 87% from 380 to 48 after a roundabout was constructed. Angle/turning crashes make up only 23% of the total crashes in the after period. Eliminating these dangerous crash types with the installation of a roundabout proves to be a significant contribution in making the intersection safer. Whereas, the angle/turning crashes were predominant at the stop controlled intersections, fixed object (32%), angle/turning (23%) and rear end (21%) crashes each were represented with similar representation, as shown. The number of fatal crashes was reduced from 12 before to zero after the installation of a roundabout. Nine of the twelve fatal crashes were angle crashes.

At roundabouts, sideswipe crashes typically occur upon entering and exiting the circulating roadway and are more likely to occur at multi-lane roundabouts. The crash results of the one two-lane roundabout within this dataset were consistent with this theory in that 23 sideswipe crashes were reported after the roundabout was in operation. Within this data set, the number of fixed object crashes was the most unexpected finding. After further evaluating the crash reports of the three intersections with the most fixed object crashes, which account for nearly 60% of all these crashes, it was determined that the fixed objects referred to in the crash reports were curbs (i.e. splitter island, central island) and sign posts (i.e. yield sign). Forty-one percent of the rear end crashes occurred at one intersection and these crashes took place consistently from year to year.

Other crash statistics of interest are the number of single-vehicle, night; alcohol related and truck related crashes occurring at roundabouts. Three intersections accounted for half of the single-vehicle crashes. Thirty-eight percent of crashes at the roundabouts were single-vehicle crashes. Night crashes were reduced slightly and crashes involving trucks remained unchanged. Although alcohol related crashes were only increased slightly, anecdotal evidence has indicated that impaired drivers have a difficult time negotiating roundabouts. In fact, one jurisdiction targets drivers under the influence at roundabout intersections. Table 5 summarizes these results.

**TABLE 5. Change in Crash Types**

| | Before | After | Change |
|---|---|---|---|
| **Angle** | 353 | 42 | - |
| **Turning movement** | 27 | 6 | - |
| **Head on** | 19 | 0 | - |
| **Fixed Object** | 19 | 68 | + |
| **Sideswipe** | 14 | 28 | + |
| **Rear end** | 61 | 44 | - |
| **Run off the road** | 4 | 7 | + |
| **Other** | 10 | 16 | + |
| **Unknown** | 4 | 1 | - |
| | | | |
| **Single vehicle** | 24 | 80 | + |
| **Night** | 83 | 71 | - |
| **Trucks** | 28 | 28 | No change |
| **Alcohol related** | 21 | 26 | + |

An area within crash reporting that does not always surface is an investigation of the types of crashes that are producing injuries. Injury crashes were reduced from 299 to 44, which is an 85% reduction. That alone is a staggering safety improvement at these intersections. Table 6 shows a comparison of the crash types and number of injury crashes that resulted from each. Two-hundred and five of those angle/turning crashes were reduced to only six after the roundabouts were installed.

Rear end injury crashes were the most prevalent at the roundabouts in the after condition (28 before and 15 after) and they either occurred when a vehicle within the circulating roadway stopped unexpectedly or a vehicle on the approach. In the after period, it was sometimes difficult to distinguish from the crash records where the crash should be coded as run-off-the-road or fixed object as in many cases they appeared to have happened simultaneously (i.e. hitting the curb). The “incomplete crash records” at five of the intersections (2-before, 3-after), did not distinguish the crash severity by crash type.

**TABLE 6. Injury Crashes by Crash Type[1]**

| | Before | After | Change |
|---|---|---|---|
| **Angle/turning** | 205 | 6 | - |
| **Rear end** | 28 | 15 | - |
| **Head on** | 8 | 0 | - |
| **Sideswipe** | 9 | 5 | - |
| **Fixed object** | 6 | 6 | No change |
| **Run off the road/Loss of control** | 2 | 7 | + |
| **Other** | 5 | 3 | - |
| **Incomplete Crash Records** | 24 | 3 | - |

[1] This table excludes fatal crashes.

In summary, the descriptive statistics show undoubtedly that the number of severe crashes was reduced (85%) at each of these intersections after roundabouts were installed and in most cases total crashes were also reduced. Another finding that can be quantified with this data set are the types of crashes occurring at roundabout are considerably different from four- and three-legged stop controlled intersections and they are the types of crashes that produce less severe crashes. The reductions in crashes at rural intersections with high-speed approaches is consistent with US crash data for all roundabouts *(6,10,15)* as well as international intersection crash data *(16)*.

## Before and After Analysis: Estimation of Statistical Significance – Empirical Bayes

The summary statistics above provide a good understanding of the intersection crash experience but lacks statistical significance of the before and after results. The next two sections provide a better understanding of the statistical significance of this data.

## Methodology

It is commonly documented in research papers that traditional methods for statistical analysis are a way of the past, sometimes called “naïve” analyses (i.e. descriptive statistics). It is becoming more mainstream to utilize sophisticated statistical approaches that before were only tackled by statisticians in the past. By no means can transportation engineers replace statisticians in doing these types of analyses, nor should they, but the Highway Safety Manual *(12)* and companion software as well as other available literature have made statistical analysis techniques more readily available. For the average jurisdiction across the United States the utilization of these more traditional methods is still in practice but hopefully these methods are being applied knowing the drawbacks (i.e. regression-to-the-mean, sample size, variation in data years) and taking them into account when considering alternative safety treatments.

Although this might be the case, we can not ignore that transportation agencies are using these “naïve” methods. It would be important to know how much different the results are between the methods. Persaud and Lyon *(17)* provided a comparison of nine empirical Bayes (EB) studies (with a range of treatments being analyzed) with a naïve analysis of the same data. The naïve analysis consisted of computing expected crashes by using the ratio of before crashes to number of years and converting that directly to the estimated number of after crashes using number of years after only. Results showed a notable difference in the reduction in the number and percentage of crashes. For example, the naïve analysis showed a 50% (278 crashes) reduction in crashes and the EB analysis showed a 40% (180) reduction based on the expected number of crashes if the treatment was not implemented. The naïve study estimate showed an inflated estimate of the expected number of crashes without treatment which then corresponds to a larger reported reduction in crashes. This paper shows evidence that the EB model approach to crash analysis to be more robust than the naïve analysis described, as it responds to regression-to-the-mean and accounts for changes in traffic volume and years of data.

Elvik *(18)* compared five different versions of EB prediction techniques, including *k+1* method, negative binomial distribution (method of moments), negative binomial (maximum likelihood) and two accident prediction models. It was concluded that for estimates of the expected number of accidents, that the EB approach represents the state-of-the-art approach to observational before-and-after studies and should be preferred to alternative approaches.

The EB before and after procedure will ideally account for regression to the mean by considering the variable traffic volumes and before and after period lengths. The most recent roundabout research has estimated the statistical significance of changes in crashes using the EB methodology. Both the Insurance Institute of Highway Safety study *(6, 19)* and NCHRP Report 572 *Applying Roundabouts in the United States (7)* accepted this method in presenting the safety results for intersections converted to roundabouts.

Equations 1 through 15 are used for the EB before and after procedure.

The change in safety at the treated intersection is shown by:

$$B - A$$ **Equation 1**

$$m = w_1(x) + w_2(P)$$ **Equation 2**

$$w_1 = \frac{P}{(k + nP)} or \frac{P}{\left(P + \frac{1}{k}\right)}$$ **Equation 3**

$$w_2 = \frac{k}{(k+nP)} or \frac{1}{k\left(P+\frac{1}{k}\right)}$$ **Equation 4**

$$k = \frac{P^2}{Var(P)}$$ **Equation 5**

$$Var(A) = A$$ **Equation 6**

Where:

| | |
|---|---|
| ***B*** | is the expected number of crashes that would have occurred in the after period without the new treatment |
| ***A*** | is the number of reported crashes in the after period |
| ***P*** | an estimate of the annual number of crashes that would be expected at intersections with traffic volumes and other characteristics similar to the one being analyzed, the regression prediction |
| ***x*** | count of crashes |
| ***n*** | years before conversion |
| ***m*** | Estimate of the expected number of crashes at the intersection before conversion |
| $w_1$, $w_2$ | Weights estimated from the mean and variance of the regression estimate |
| ***k*** | a constant for a given model and is estimated from the regression calibration process |

The significance of the difference *(B-A)* is established from this estimate of the variance of B and assuming, on the basis of a Poisson distribution of counts, that *Var (A) =A.*

The expected annual number of crashes during the before period is estimated as:

$$m_b = \frac{(k+x_b)}{\left(\frac{k}{P+y_b}\right)}$$ **Equation 7**

$$R = \frac{P_a}{P_b}$$ **Equation 8**

$$m_a = R \text{ x } m_b$$ **Equation 9**

$$B = m_a x\, y_a$$ **Equation 10**

$$Var(B) = \frac{(m_a)x(R \text{ x } \mathrm{y_a})^2}{\left[\left(\frac{k}{P}\right) + y_b\right]}$$ **Equation 11**

$$\pi = \sum B \text{ and } \lambda = \sum \mathrm{A} \ \therefore \ \delta = \pi - \lambda$$ **Equation (12a,b,c)**

$$Var(\delta) = \sum Var(B) + \sum Var(A)$$ **Equation 13**

$$\theta = \frac{\left(\frac{\lambda}{\pi}\right)}{\left[1 + \left(\frac{Var(\pi)}{\pi^2}\right)\right]}$$ $100(1-\theta)$ is the percent change in crashes **Equation 14**

$$Var(\theta) = \theta^2 \frac{\left[\left(\frac{Var(\lambda)}{\lambda^2}\right) + \left(\frac{Var(\pi)}{\pi^2}\right)\right]}{\left[1 + \frac{Var(\pi)}{\pi^2}\right]^2}$$ **Equation 15**

Where:

| | |
|---|---|
| $\boldsymbol{R}$ | is the ratio of the after period to the before period regression predictions |
| $\boldsymbol{y_a, y_b}$ | length of the after (before) period in years |
| $\boldsymbol{\delta}$ | the reduction of the expected number of crashes |
| $\boldsymbol{\theta}$ | a biased estimate of the index of effectiveness, index of effectiveness |

### *Safety Performance Functions (Regression Models)*

As indicated above, the EB analysis requires the use of a safety performance function (SPF) to conduct the estimation. Generally SPF's take the form of Equation 16. It is ideal that the SPF be developed specifically for the intersection and safety data from the jurisdiction where the data is being compared, however this process requires a significant undertaking, especially for a data set that has data from six different states. The resources to create specific SPF's for this data were not available for this research. Despite this limitation, the literature presents several models *(20,21,22)* that have been developed using intersection and crash data from the state of Minnesota. The robustness of Minnesota crash and intersection data and with a Minnesota intersection represented in the data, the use of this model was deemed appropriate for use with this analysis. Additionally, utilizing SPF's already established within the literature is an accepted practice that is seen in both Persaud et al. *(5)* and Rodegerdts et al. *(7)*.

$$\log(\mu) = \alpha_0 + \alpha_1 x \log(DEV) \text{ or } \mu = \exp(\alpha_0) x DEV^{\alpha_1}$$

**Equation 16**

Bonneson and McCoy *(20)* developed a model to predict annual expected crash frequency for two-way stopped controlled intersections on rural highways. The data set used to develop this model included 125 rural intersection in Minnesota where 108 of those intersections were on two-lane highways with the majority of the major road ADT's under 4,000 (min -430; max -37,900) and the mean crashes per year were 0.67 (min-0; max-7). Although the current data set has a higher mean traffic volume (6,300 AADT) and a higher number of crashes/year (5 crashes/year) it is assumed that this Bonneson and McCoy model represents a similar rural intersection population for the states in this study. It should also be noted that many of the intersections included in the current data sets have a higher than average number of crashes and thus is one of the reasons they were targeted for a new intersection treatment.

The following model shown in Equations 17a and 17b was developed by Bonneson and McCoy *(20)* for crashes per year at four-legged intersections with two-way stop controlled intersections.

$$E(m) = 0.692\left(\frac{T_m}{1{,}000}\right)^{0.256}\left(\frac{T_c}{1{,}000}\right)^{0.831}$$

**Equation 17a**

$$E(m) = 0.000379(T_m)^{0.256}(T_c)^{0.831}$$

**Equation 17b**

Where :
$E(m)$ = expected crash frequency per year
$T_m$ = major road traffic volume
$T_c$ = minor road traffic volume

Vogt and Bared *(21,22)* similarly modeled both rural four- and three-legged intersections with stop control. The research also used intersection and crash data from Minnesota and Washington State, however the final negative binomial models only included the Minnesota data, as it was determined more robust. The Vogt and Bared models for total crashes per year contain more explanatory variables than the Bonneson and McCoy model, as shown in Equations 18 and 19:

Crashes per year for four-legged intersection of two-lane rural roads, stop controlled on the minor.

$$y = (ADT1)^{0.603} x (ADT2)^{0.609} x e^{-10.4} x e^{(0.0449HI + 0.289VCI + 0.01875SPDI + 0.124ND - 0.0049HAU)}$$ **Equation 18**

Crashes per year for three-legged intersection of two-lane rural roads, stop controlled on the minor.

$$y = (ADT1)^{0.805} x (ADT2)^{0.504} x e^{-13.0} x e^{(0.0339HI + 0.290VCI + 0.0285SPDI)} x e^{(0.173RHRI + 0.267RT + 0.0045HAU)}$$

**Equation 19**

Where:

| | |
|---|---|
| **y** | predicted mean number of intersection or intersection related crashes within 250 ft of the intersection |
| **ADT1** | average two-way major road traffic in vehicles per day |
| **ADT2** | average two-way minor road traffic in vehicles per day |
| **HI** | sum of degree of curve in degrees per 100 feet for each horizontal curve on major road any portion of which is 250 ft of the intersection center, divided by the number of curves |

| | |
|---|---|
| **VCI** | sum of the absolute change in grade in percent per 100 ft for each crest curve on major road any portion of which is within 250ft of the intersection center, divided by the number of such curves |
| **SPDI** | average posted speed in miles per hour on the major road in vicinity of the intersection |
| **RHRI** | Average Roadside Hazard Rating within 250 ft of intersection center along major road |
| **RT** | 0 if no right turn lane on major, 1 if right turn lane exists on major road |
| **HAU** | angle in degrees between the increasing direction of major road and minor road minus 90 degree, multiplied by 1 if minor road is to the right and by -1 if minor road to the left |

No injury models were provided by Bonneson and McCoy, however an approximate model *(19)* can be derived using the Minnesota four-legged intersection's ratio of injury to total crashes from Vogt and Bared *(21,22).* The equation above then takes the form as shown in Equations 20, 21, and 22:

$$InjuryCrashes/Year = 0.000194x(MajorRoadAADT)^{0.256}\,x(MinorRoadAADT)^{0.831}$$

**Equation 20**

Injury crashes per year for four-legged intersection of two-lane rural roads, stop controlled on the minor *(21,22).*

$$y = (ADT1)^{0.6330}\,x(ADT2)^{0.6229}\,x\,e^{-10.78}\,x\,e^{(0.0729HI+0.2789VCI+0.0112SPDI-0.1225RHR+0.124ND+0.0451RT-0.0043HAU)}$$

**Equation 21**

Injury crashes per year for three-legged intersection of two-lane rural roads, stop controlled on the minor *(21,22).*

$$y = (ADT1)^{0.8122} x (ADT2)^{0.4551} x\, e^{-13.04} \\ x\, e^{(0.034HI + 0.187VCI + 0.016SPDI)} x\, e^{(0.207RHR - 0.012ND + 0.362RT + 0.0051HAU)}$$

**Equation 22**

## Analysis

Initially both the Bonneson and McCoy, and Vogt and Bared SPF models were used to predict the crash frequency for total and injury intersection crashes at the four-legged intersections and only the Vogt and Bared model SPF was used for the three-legged intersections. The Bonneson and McCoy model better predicted the total and injury crashes for the four-legged intersections, and therefore was used in the EB estimation of significance

Once the best available SPF models were determined, another technique used to more closely represent the specific data set, when SPF's are not available for the specific jurisdictions, is to recalibrate these SPF's *(7,23)*. This is done by using only the crash data one year prior to the installation of the roundabout, to attempt to avoid a random high crash count in the before period that would overestimate the safety performance *(7)*. A yearly calibration factor, $C_{i,,}$ is determined as shown in Equation 23 and then is added as a multiplier for the SPF.

$$C_i = \frac{\sum observed\_accidents_i}{\sum predicted\_accidents_i}$$

**Equation 23**

## Results

The results using the Bonneson and McCoy model and the calibrated Bonneson and McCoy, as described above, were evaluated to determine how well the model fit the data represented in this study. On an individual basis, nine of the intersections' average total observed crashes per year were predicted within 2% of the un-calibrated model, five intersections were predicted within 3% of the calibrated model, four intersections were over predicted by both models between 12 and 36%, and one intersection was estimated the same for both models. For injury crashes, nine of the intersections' average observed injury crashes per year were predicted within 1% of the un-calibrated model and seven intersections' average observed injury crashes per year were within 2% of the calibrated model. The breakdowns of these comparisons are shown in Appendix E.

The before and after analysis results of rural roundabouts with high-speed approaches are shown in Tables 7 and 8. A range for the estimates is shown, representing both the calibrated and un-calibrated safety performance functions from Bonneson and McCoy. Results for both the calibrated and un-calibrated models are presented here, as there was not overwhelming evidence to choose one over the other.

Both of the estimates of the percentage reduction in crashes for total and injury (including possible injury) crashes ranged from 62% to 67% and 85% to 87%, respectively. These results are consistent with the findings of the nine intersections in the NCHRP Report 572. The EB estimate of crashes that is expected if roundabouts were not installed is shown for the 98 data years in which actual before and after data were available. With longer study periods, as is the case with these data, there are more opportunities for crashes to occur. Consequently, the observed crash history is likely to be more meaningful and the model prediction less important so, as the predicted crashes increase, the EB method places more weight on the number of crashes that actually occur *(12).*

Only considering intersections with two-way stop control prior to the conversion to a single-lane roundabout, these results show a slightly higher reduction in total and injury crashes from 71% to 74% and 87% to 89%, respectively. The other sub-categories, two-lane roundabouts and one-way stop control before conversion, only had one and two intersections, respectively, in each of the categories. So although, we can consider those results at the disaggregate level, they may not be representative of a larger subset of the same types of intersections converted to roundabouts. Additional intersections would be needed to better represent these categories.

**TABLE 7 . Before and After Crash Comparison Results for the Calibrated Model**

| **Control Before** | **Sites** | **Lanes** | **Crashes recorded in after period** | | **EB estimate of crashes expected without roundabouts** | | **Index of Effectiveness and Point Estimate of the Percentage Reduction in Crashes** | |
|---|---|---|---|---|---|---|---|---|
| | | | **All** | **Injury** | **All** | **Injury** | **All** | **Injury** |
| **All** | 19 | All | 212 | 44 | 631.5 | 347.3 | .335<br>67% | .126<br>87% |
| **Two-way stop (4 legs)** | 17 | All | 197 | 42 | 613.6 | 341.1 | 0.322<br>68% | .122<br>88% |
| | 16 | 1 | 149 | 35 | 580.3 | 324.4 | .256<br>74% | .107<br>89% |
| | 1 | 2 | 48 | 7 | 33.3 | 16.6 | 1.41<br>-41% | .405<br>60% |
| **One-way stop (3 legs)** | 2 | 1 | 14 | 2 | 17.9 | 6.3 | .739<br>26% | .276<br>72% |

**TABLE 8. Before and After Crash Comparison Results for the Un-Calibrated Model**

| Control Before | Sites | Lanes | Crashes recorded in after period | | EB estimate of crashes expected without roundabouts | | Index of Effectiveness and Point Estimate of the Percentage Reduction in Crashes | |
|---|---|---|---|---|---|---|---|---|
| | | | All | Injury | All | Injury | All | Injury |
| **All** | 19 | All | 212 | 44 | 552.5 | 283.7 | .383<br>62% | .15<br>85% |
| **Two-way stop (4 legs)** | 17 | All | 197 | 42 | 536.5 | 278.7 | .368<br>63% | .15<br>85% |
| | 16 | 1 | 149 | 35 | 507.3 | 265.1 | .29<br>71% | .13<br>87% |
| | 1 | 2 | 48 | 7 | 29.1 | 13.6 | 1.61<br>-61% | .49<br>51% |
| **One-way stop (3 legs)** | 2 | 1 | 14 | 2 | 16.0 | 5 | .828<br>17% | .35<br>65% |

## Prediction Modeling Considerations and Development

According to Ott and Longnecker *(24)*, the Poisson distribution is commonly used for estimating the probability of occurrences of an event that takes place randomly over a specified time period, as long as the assumptions are not unreasonably violated. It assumes that crashes typically occur one at a time and crashes are independent of one another at an intersection. This assumption is consistent with the Maiou and Lum *(25)* assessment when they concluded that the Poisson regression and negative binomial models are able to effectively explain statistical properties of crashes because of its' ability to process discrete random variables compared to conventional linear regression models.

### Poisson Model

The Poisson model has the form shown in Equation 24.

$$\mu_i = e^{(\beta_0 + \sum_{j=1}^{n} x_{ij}\beta_j)}$$ **Equation 24**

$\mu$ = mean number of crashes to be expected at site $i$

$x_{i1},\ldots x_{in}$ = values of the highway variables at site $i$

$\beta_0, \beta_1, \ldots. \beta_n$ = coefficients to be estimated by the model

The variance in the number of accidents at a site is equal to the mean $u_i$.

## Negative Binomial Model

The negative binomial model has the form shown in Equation 25.

$$P(y_i) = \frac{\Gamma\left(y_i + \frac{1}{K}\right)}{y_i!\,\Gamma\left(\frac{1}{K}\right)} x \left(\frac{Ku_i}{1+Ku_i}\right)^{y_i} x \left(\frac{1}{1+Ku_i}\right)^{\frac{1}{K}}$$ **Equation 25**

$K$ = overdispersion parameter

The variance of the negative binomial model is shown in Equation 26:

$$u_i + K(u_i)^2$$ **Equation 26**

## Model Appropriateness

Both the Poisson and negative binomial models are appropriate for crash data, however, it is still important to determine if one model is more adequate in than the other. Two easy ways to measure the accuracy of the Poisson model are deviance and Pearson Chi-Square. If the Poisson model is adequate, the expected value for both deviance and Pearson Chi-Square (value/degrees of freedom) are close to one, otherwise the validity of the model may be in question. A ratio (greater than one) may indicate an over-dispersed response variable. In this case the deviance can be scaled to one for the Poisson model, however this still leaves some uncertainty in the model as this is just a correction term *(26)* for testing the parameter estimates under the Poisson model.

The negative binomial model can account for the potential over-dispersion. The negative binomial dispersion accounts for overdispersion because its' variance is always greater than the variance on a Poisson distribution with the same mean *(26)*. As *k* approaches zero, the negative binomial model approaches the Poisson model.

## Variables

Both total and injury crashes were modeled using the following explanatory variables.

| | |
|---|---|
| **logDEV** | Log of Intersection daily entering volume |
| **LEGS** | Number of approach legs |
| **SPDMAX** | Maximum posted speed limit on major approach |
| **YEARSBA** | Offset variable – number of crash data years |

This data set included two intersections with three approaches before and after the conversion of the roundabout and two intersections with four approaches before and five approaches in the after condition.

The statistical before and after study was designed to provide a more robust interpretation of the crash data than the descriptive statistics at rural roundabouts on high-speed roadways. The dataset for rural roundabouts on high speed roadways is the largest available, providing over 98 years of total before crash data and 98 years of total after crash data for the intersections combined. SAS 9.1.3 *(27)* was used to derive a regression model for the rural roundabout crash data.

The deviance and Pearson Chi Square divided by the degrees of freedom for the Poisson model was not close to one therefore it is expected that the model may be overdispersed and not a good fit for the data. Subsequently, the negative binomial model resulted in deviance and Pearson Chi-Square values divided by degrees of freedom near one for the initial models and thus were assumed to be satisfactory models for this data. No subsequent models were explored.

The number of years before and after was established as an offset variable in the model, as they are not constant and fluctuates between intersections and within intersections from the before to after period. Additionally, because each site was included in the analysis two times, once in the before period and once in the after period, a repeated subject entity had to be included in the analysis. In the before and after crash comparisons, a repeated subject code was needed because each intersection was represented twice in the model, before and after. The “repeated” statement was added to the SAS code in this case and as a result the standard errors are underestimated in the initial model *(27)* and a generalized estimating equation (GEE) is produced for the final model. The repeated code was not needed for the after only model.

Although both major road DEV and minor road DEV were available, the model was stronger when only DEV for the intersection was used. Separating the major and minor road traffic volumes in the model indicated that the minor DEV was not a significant variable in the model. The combined DEV indicated a better fit model.

### *Results/Statistical Inference*

The statistical results show the estimated reduction in the total crashes after the roundabout was constructed, 63%, is statistically significant (p-value <0.0001) and the estimated reduction in the injury crashes, 88%, is also statistically significant (p-value <0.0001). The regression estimate also showed the changes in the crash types after the roundabout was constructed showed a statistically significant (p-value <0.0001) reduction in the number of angle crashes, 83%. The 15% reduction in rear end crashes, was not statistically significant (p-value 0.4489), however the 366% increase in fixed object crashes was statistically significant (p-value 0.0005) and the 179% increase in sideswipe crashes was not statistically significant (p-value 0.0579) however this increase was just outside the 95% confidence level. The reduction in the PDO crashes was not significant.

Fourteen intersections had detailed enough crash data to estimate the statistical significance of the changes on injury crashes by type. A 91% reduction in injury-angle crashes after roundabouts were constructed which was statistically significant (p-value <0.0001). 46% reduction in injury-rear end crashes was not statically significant (p-value 0.0938) at the 95% confidence level. Table 9 summarizes these results and the SAS output is shown in Appendix F.

**TABLE 9. SAS Contrast Estimate Results (After vs. Before)**

| Difference in mean crashes | Estimate of the difference in percentage | Level of significance (p-value) | Significant? |
|---|---|---|---|
| **Total crashes** | 63% | <0.0001 | Yes |
| **Injury crashes** | 88% | <0.0001 | Yes |
| | | | |
| **Angle crashes** | 83% | <0.0001 | Yes |
| **Rear end crashes** | 15% | 0.4489 | No |
| **Sideswipe crashes** | 179% | 0.0579 | No |
| **Fixed object crashes** | 366% | 0.0005 | Yes |
| | | | |
| **Injury-angle crashes** | 91% | <0.0001 | Yes |
| **Injury-rear end crashes** | 46% | 0.0938 | No |

## Rural Roundabout Prediction Models

The NCHRP Report 572 *(7)* provides intersection prediction models based on United States roundabout data. The general models are used for estimating the expected number of crashes at an existing or planned roundabout as a function of the number of approach legs, number of circulating lanes and traffic volumes. There is not, however, intersection-level safety prediction models for total crashes and injury crashes for rural intersections with high speed approaches. This research set out to develop these models for this particular intersection environment and also determine how closely the general roundabout crash prediction models developed in NCHRP Report 572 *(7)* estimated this data set. Both fatal and possible injury crashes were used to determine an injury crash prediction model for rural roundabouts. All nineteen roundabouts, regardless of the number of legs and traffic volume, were included in one model.

For both the total crash and injury crash prediction models, one intersection acted as an outlier in the model (i.e. the total number of crashes was nearly 10 times higher than each of the other intersections) and thus produced a model that was skewed towards the outlier. This roundabout was the only roundabout that the single approach lanes were widened for a two-lane roundabout. It is expected that two-lane roundabouts would have higher total crashes than single-lane roundabouts. After the one intersection was removed, the prediction models better fit the actual intersection results. The final models are shown in Equations 27 and 28. Figures 3 and 4 also show the predicted number of total and injury crashes relative to the predictive model.

Assessing the goodness of fit for the models showed that the negative binomial model resulted in deviance and Pearson Chi-Square values divided by degrees of freedom near one for the total and injury crash models and thus were assumed to be satisfactory models for this data. With such low crash experience at roundabouts and only eighteen intersections in the final model, this model will likely be improved as the number of rural roundabouts increases. The SAS output is shown in Appendix F.

Total crashes/year = $e^{-6.1810} \times (DEV)^{0.7274}$ dispersion factor, k=0.1525 **Equation 27**

Injury crashes/year = $e^{-21.0032} * (DEV)^{2.1703}$ dispersion factor, k=0.1204 **Equation 28**

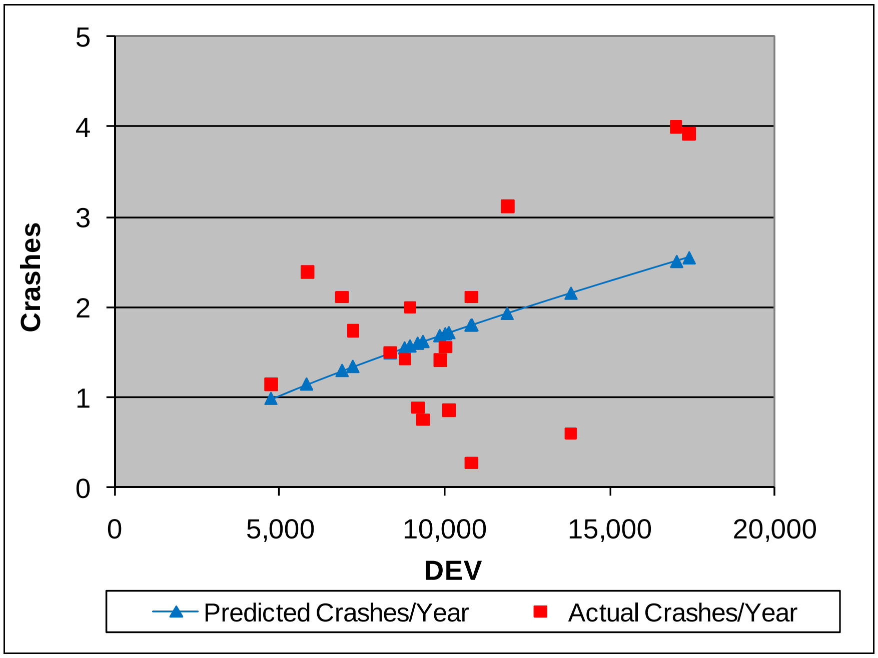

FIGURE 3. Total crashes predicted and observed

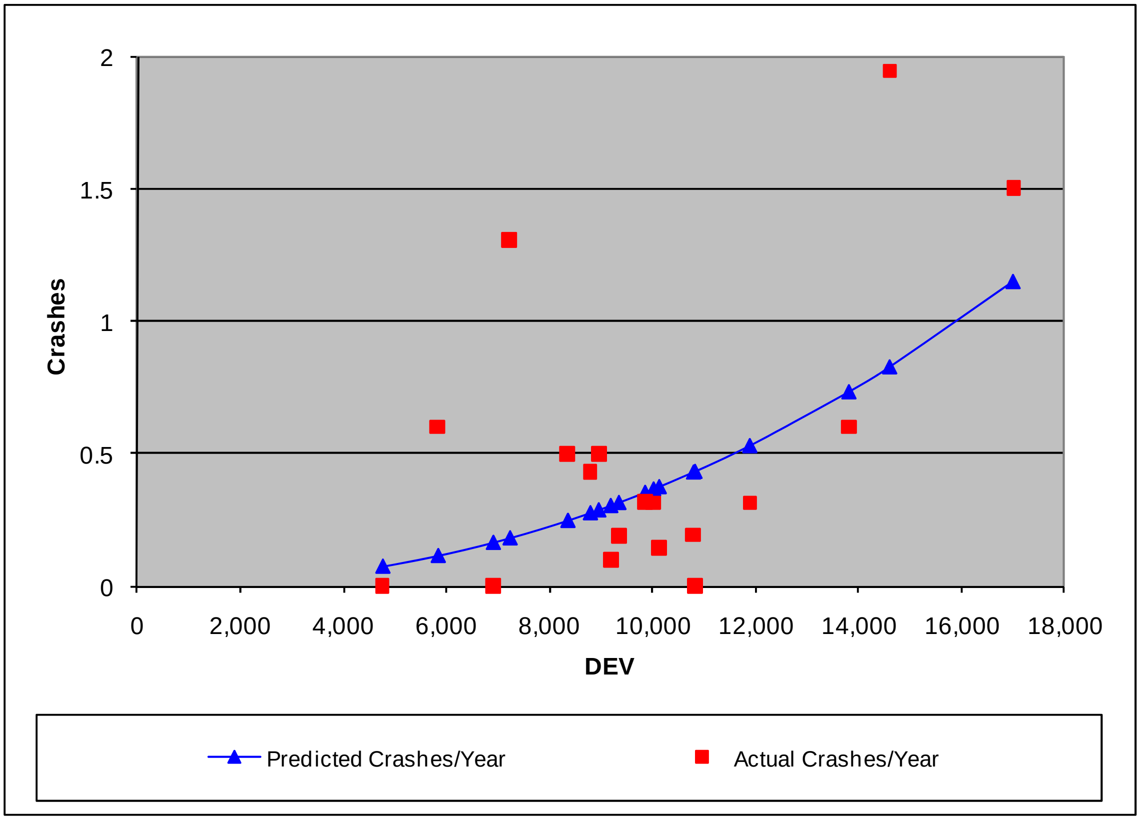

FIGURE 4. Injury (fatal and possible) crashes predicted and observed

Providing a comparison of these crash prediction models, specific to rural roundabouts, to the general roundabout prediction equations provided in NCHRP Report 572 allows for an evaluation. The findings show that on average the NCHRP Report 572 total crash model (for 4 legs) slightly over predict crashes (by 0.57 crashes/year) compared to this new model where crashes are on average slightly under predicted (by 0.07 crashes/year). For the injury crash models, the NCHRP Report 572 general model (for 4 legs) and this new model are very similar in that they both slightly under predict crashes (0.17 and 0.1, respectively). Figures 5 and 6 show the prediction equations compared graphically along with the actual crash data in this data set. (Note: Nine of the roundabouts from NCHRP Report 572 research were included in this data set.)

The NCHRP Report 572 five-legged total crash model over predicts the two five-legged rural roundabouts in this data set by approximately 2 crashes/year. The NCHRP Report 572 three-legged total crash model under predicts the two three-legged rural roundabouts in this data set by about 0.5 and 2 crashes/year, respectively. Similarly, the NCHRP Report 572 injury crash models overpredict the five-legged rural roundabouts by approximately 0.5 injury crashes/year and under predict the injury crashes at three-legged rural roundabouts in this study by slightly less than 0.5 an injury crash/year.

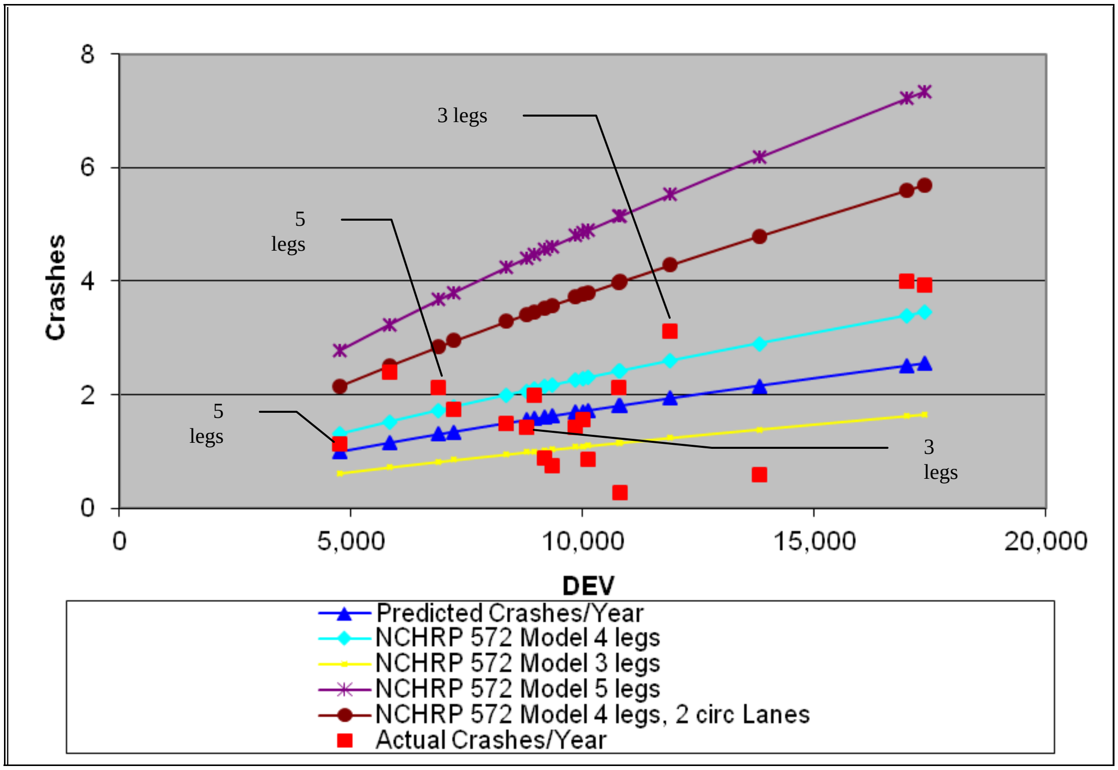

FIGURE 5: Comparison of predicted and observed total crash models

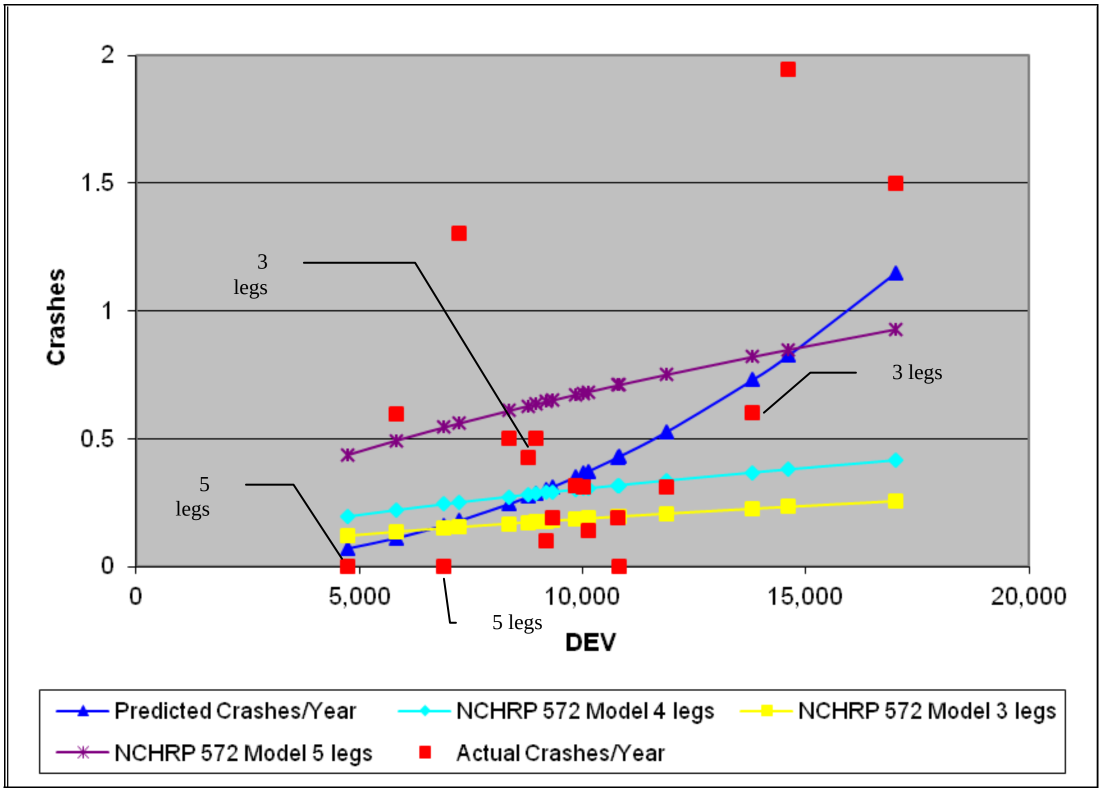

FIGURE 6: Comparison of predicted and observed injury crash models

## Summary and Conclusions

Transportation agencies are in need of intersection treatments that solve crash problems, not just change the crash experience. Roundabouts have proven to be effective in urban and suburban environments in the United States, but little has been reported on their effectiveness in rural environments with high-speed roadways. Roundabouts can provide an effective solution to rural intersections with high-speed approaches that have a poor crash history, and more specifically, an intersection with a history of injury crashes. The nature of the roundabout simply changes the dynamics of vehicles traversing the intersection. Drivers must slow their vehicles to a uniform speed and make an independent decision on how and when to proceed through the circular intersection, whose geometry is such that injury producing crashes (i.e. angle or T-bone) are virtually eliminated. Several states in the United States have embraced the safety benefits that rural roundabouts provide and they continue to increase the number of roundabouts on high-speed roadways.

A negative binomial regression model was created to estimate the effectiveness of roundabouts in these rural locations. The findings of this research show statistically significant reductions (95% level) in the number of total and injury crashes after roundabouts are installed at rural intersections on high-speed roadways. The reductions in total and injury crashes are 63% and 88%, respectively. Both of these statistics indicate a slightly higher reduction in total and injury crashes than the general statistics provided in NCHRP Report 572, where the estimate of total crash reduction is 35% and injury crash reduction is 76%. There are several reasons that this may be the case, 1) rural roundabouts tend to be single lane roundabouts so the total number of crashes sees a larger reduction, and 2) rural roundabouts tend to be constructed in locations with a poor crash history which might also reduce the crash experience more than urban and suburban roundabouts.

A before and after empirical Bayes estimation was also conducted. The index of effectiveness and percent reduction in crashes were consistent with the negative binomial regression model results, indicating a 62 to 67% reduction in total crashes and an 85 to 87% reduction in injury crashes at these rural intersections.

Dissecting the crash data further for 14 of 19 intersections showed that roundabouts change the types of crashes at intersections and reduce the number of injury type crashes. Angle crashes proved to be the most injury producing type of crashes at these intersections. Not only were potentially dangerous angle crashes decreased by 83%, but the number of actual injury producing angle crashes were reduced by 91%, both statistically significant reductions. Rear end crashes was the second most likely crash type to produce an injury and although the number of injury rear end crashes was reduced by 46%, the finding was not significant and the 95% level.

Furthermore, now planning level total and injury crash prediction models are available for rural roundabouts on high speed roadways. This model supplements the research presented in NCHRP Report 572, by providing more data and rural roundabouts specific models to the literature.

Finally, this research provides additional evidence that the safety benefits of roundabouts in rural environments are similar to what has been documented in urban areas in the United States.

## Limitations

The analyses for the data are limited to the nineteen intersections included in this study. However, when this analysis was conducted these were the only nineteen roundabouts that met the characteristics and had enough before and after data to be evaluated. Additionally, the crash prediction models fit the data better than the NCHRP Report 572 models though the data presented here were used to create the model. The models presented here need to be calibrated and/or validated with rural roundabouts not included in the original data set.

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# CHAPTER 6. APPROACH SPEED EFFECTS AT RURAL HIGH-SPEED INTERSECTIONS: ROUNDABOUTS VS TWO-WAY STOP CONTROL

A paper to be submitted to the *American Society of Civil Engineers Journal of Transportation Engineering.*

Hillary Isebrands, Shauna Hallmark and Neal Hawkins

## Abstract

Speed can increase the risk injury producing crashes, especially at intersections where vehicles may be approaching an intersection and entering an intersection with high speed differentials. It is known that roundabouts force all drivers to reduce their speed in the intersection; however, no advanced approach speed data was available for roundabouts with high speed approaches to verify this phenomenon. This research performed a comparative evaluation of the difference in the average approach speeds between rural roundabouts and rural two-way stop control intersections and between rural roundabouts with and without rumble strips on the intersection approaches. Approach speed data proved that drivers are able to slow down in advance of roundabouts on rural roadways and the mean speeds at 100 ft from the yield line were 2.5 mph lower than mean speeds at 100 ft from the stop bar at stop controlled approaches. Additionally, a comparison between roundabout approaches with and without rumble strips showed mean speeds 4.3 mph and 3.3 mph lower at 100 ft and 250 ft from the yield line, respectively, for the approaches with rumble strips; however, the variation in speeds increased with the introduction of rumble strips.

## Introduction

"Drivers, vehicles and roadways are complicated co-contributors in traffic accidents." *(1)*. This statement holds true over 40 years later, despite the advancements we have seen in vehicle safety and improvements in roadway guidelines and designs. Regardless of the engineering advances that have been made, driver error continues to be a major contributor to motor vehicle crashes so roadway and intersection designs should be forgiving to allow roadway users an opportunity to recover. Design can reduce the incidence of human error, chance of human error resulting in a crash and the severity of the consequences of crashes *(2)*.

Fatal crashes still occur in abundance on our roadways and are over-represented on rural roadways. National statistics show that the fatality rate on rural non-interstate roads is 2.35 per 100 million vehicle miles traveled (MVMT). That is nearly three times higher than the urban non-interstate roadway fatality rate *(3)*. Nearly 40 % of those fatalities (2,830) are at rural intersections. The percentage of fatalities occurring at intersections remains steady despite vehicle miles traveled declining in recent years which indicates that fatal crashes at intersection are declining at a pace consistent with crash trends but we still are not seeing any significant reductions with the countermeasures that are being implemented. More alarming is that approximately one-third of all injury crashes and 15% of all fatal crashes occur at traffic signals and stop signs *(4)*.

The type of control and/or design at a rural intersection has varying levels of safety and risk. All way stop control intersections typically have safe crash histories however there is still some risk of a driver running a stop sign. Two way stop control intersections, by design, promote free flow speeds on the major route while the minor road must stop;

introducing risk if a driver runs a stop sign. Similarly, a signalized intersection on high speed rural roadway assigns right of way at the intersection, with actuation on the minor road. Speed differentials at stop controlled and signalized intersections introduce the risk of high speed, angle crashes which tend to increase the likelihood of a severe injury.

Speed is often a contributing factor to intersection crashes *(5)*, however, only a modest number of studies evaluate speeds at intersections and its' relationship to safety *(6)*. Speed, speed variances, and deceleration rate have been identified as surrogates for crash risk *(7,8,9,10,11,12,13)*. Additionally, surrogate events to crashes, like speed, may provide complementary information to decision makers *(14)* when determining an appropriate intersection countermeasure that yields the highest benefits.

One forgiving engineering solution that addresses speeds at intersections and that has only recently been recognized by transportation agencies is the modern roundabout, hereinafter referred to as roundabout. The geometric features of a roundabout slow *all* vehicles approaching and entering an intersection. This reduces speed variances between vehicles on the same approach as well as on the other approaches and significantly reduces the probability of right angle - injury prone crashes.

Roundabouts slow *all* approach traffic entering the intersection to a consistent range of speeds – speeds are controlled by the geometry of the roundabout intersection. Although, little published research has focused on the overall safety effectiveness of roundabouts on high speed roadways two studies (*15,16*; See Chapters 4 and 5 of this dissertation) show substantial reduction in injury crashes at roundabouts . Isebrands *(16)* reports the average injury crash frequency was reduced by 84%, average injury crash rate was reduced by 89%, angle crashes were reduced by 86%, and fatal crashes were reduced by 100% at seventeen rural roundabouts with high speed approaches.

In 2008, the Federal Highway Administration (FHWA) issued a memorandum, *Consideration and Implementation of Proven Safety Countermeasures (17)*, which highlighted modern roundabouts as one of these nine proven safety countermeasures. The excerpt below represents the FHWA's position regarding roundabouts:

> "Roundabouts are the preferred safety alternative for a wide range of intersections." …"Roundabouts should also be considered for all existing intersections that have been identified as needing major safety or operational improvements. This would include freeway interchange ramp terminals and rural intersections."

This research used field data from six rural intersections (four roundabouts and two two-way stop controlled) to evaluate the differences in the approach speeds at roundabouts and two-way stop controlled intersections with different advanced traffic control.

## Study Description

### Need for Research

Although modern roundabouts have gained recognition as a viable intersection alternative that improves intersection safety and operations, many transportation agencies are still reluctant to construct roundabouts in rural locations on high-speed roadways (greater than 40 mph). Numerous government agencies and citizens argue that roundabouts are for urban and suburban environments and are not appropriate on rural roadways. Much of the speculation comes from comments such as these

- “Drivers are not used to having to *slow down* on that roadway.”
- “I never had to slow down at that intersection before and if you construct a roundabout I am going to have to slow down and it will take me longer to get home.”
- “How will drivers know there is a roundabout ahead so they can *slow down*?”
- “Drivers won’t be able to navigate the intersection are we are going to see more crashes than we had before.”
- “Roundabouts might be appropriate in other states but we have adverse weather conditions here (i.e. snowy, foggy, and rainy regions) and they just are not going to work.”

Before and after safety data is now available for rural roundabouts on high speed roadways which shows between 84% and 87% reduction in injury crashes *(15,16)*, but concerns still remain on the ability of drivers to slow down in advance of a roundabout in order to navigate it safely. The only speed data that has been collected at roundabouts was a part of the NCHRP Report 572, *Roundabouts in the United States (15).* Although speed based prediction model for roundabouts showed promise from this research, the dataset was not robust enough to recommend a safety prediction model at this time. Additionally, the number of roundabouts and approaches at rural locations was limited and approach speed data was only calculated at locations 200 ft from the yield and at the yield line.

Looking beyond roundabouts, the FHWA is supporting strategies to improve driver awareness on intersections approaches, of traffic control to minimize crash frequency and severity, reduce operating speeds on intersection approaches *(18).* Speed data in general have not extensively been studied on intersection approaches. A 2008 study, that evaluated three potential speed reduction treatments (transverse pavement markings, rumble strips, dynamic warning signs) at high speed intersections, concluded that “additional research is needed to fully understand the effects that speed reduction treatments and reduced speed may have on safety” *(6)*.

## Research Objectives

Roundabouts on rural high speed roadways can improve the overall safety of the intersection and dramatically reduce the number of serious injury and fatal crashes. The primary objective of this research was to perform a comparative evaluation of the difference in the average approach speeds/speed profiles between roundabouts with and without rumble strips and between roundabouts and two-way stop control intersections, neither with rumble strips. The second objective of this was research was to determine if speed and speed variation on the approaches is an appropriate/viable crash surrogate for intersection safety. The third objective of this research was to consider the crash data, more specifically, the types of crashes, contributing factors to the crashes and severity of crashes amongst the intersections and determine if a relationship between approach speed characteristics and crash data could be established.

## Available Literature

### *Safety Experience at Intersections on High Speed Roadways*

Prior intersection safety studies have shown fairly inconsistent results in terms of advanced traffic control that yields the best safety results at rural intersections on high speed roadways. What is known is that angle crashes dominate the highest frequency of crash types at rural intersections followed by rear end crashes *(19,20)*. Furthermore, angle crashes have a higher risk of causing severe injuries.

Research conducted by Agent *(21)* that evaluated countermeasures at stop controlled intersections in a before and after study. Sixty-five intersections on rural high-speed roadways in Kentucky identifying types of traffic control (stop signs, intersection beacon, signal control), types of accidents, contributing factors and making recommendations for countermeasures at such locations. Intersections that were converted from stop control to stop control with a beacon (eleven), from stop control to signal control (sixteen) and conversions from stop control with beacon to signal control (twenty) showed inconsistent results in before and after safety data. However, several interesting findings were reported for these rural intersections, 1) both the stop controlled and stop controlled with the beacon had higher percentages of angle crashes than the statewide average, 2) injury crashes accounted for 37 percent, 40 % and 34 % of the total crashes for stop controlled, stop controlled with beacon and signal control, respectively, while the statewide average for all intersection is 24 percent, indicating that intersections in these environments are at higher risk for injury crashes, and 3) the most common comments on the crash report were that after stopping the minor road the driver did not see the approaching vehicle (when sight distance was okay), the minor road vehicle did not stop, there was not enough time to stop when the signal turned red, and disregard for traffic signal. The research concluded that advance intersection warning is critical for drivers.

A similar study done in California identified approach characteristics that may affect crash rates at high-speed, isolated signalized intersections *(8)*. Left turn phases for signal, raised medians, wide paved shoulders, and an advance warning sign with a flashing beacon were significantly correlated to lower crash rates. The authors conclude that in order to minimize the potential surprise of drivers that effective advance warning, efficient traffic control and safe geometric features are necessary.

Thompson et al. *(22)* states that the number and severity of crashes at rural stop controlled intersections could be enhanced with the use of traffic control devices and found that rumble strips initially reduce approach speeds at a statistically significant level but this research did not address the long term safety effectiveness of transverse rumble strips.

Preston and Storm *(23)* found that right angle crashes were the most predominant type of crash at rural thru-stop controlled intersections in Minnesota and that these crashes were producing 62% of the series injury crashes and 71% of the fatalities. Fifty-seven percent of the right angle crashes occurred when the vehicle stopped pulled out in front of the vehicle with the right of way and another 26% of the crashes involved vehicles that ran the stop sign, these crashes were more severe. The field review indicated that more, brighter and larger stop signs and warning signs (i.e. use of large stop ahead sign) appear to reduce the number of running the stop sign crashes. Intersections with lighting and stop ahead pavement marking also had less crashes. A systematic approach of these potential mitigation strategies is suggested.

### *Roundabout Safety Experience*

The first quantitative roundabout crash data and safety analysis results were published as a part of NCHRP Report 572 *Roundabouts in the United States (15)*. An empirical bayes (EB) statistical analysis showed a 35 % reduction in overall crashes and a 76 % reduction in injury crashes at 55 modern roundabouts. Furthermore, at nine rural locations the total crash reduction was found to be 71 % and the injury crash reduction was reported at 87 percent. A study of nineteen rural roundabouts on high speed roadways found similar results with an 84% reduction in injury crashes *(16)*.

Internationally, the safety record of roundabouts on high speed roadways has been consistent. New Zealand, Australia, United Kingdom and Belgium indicate that roundabouts have a particularly good safety record in high-speed environments compared to traditional intersection traffic control *(24,25,26,27)*.

A before and after roundabout comparison of 122 intersections in Belgium by Antoine *(25*) showed a 42% decrease in injury crashes. The reduction varied by environment, 15%, 46% and 50% reduction in urban, suburban and open country (rural environment), respectively. A reduction of 15% of crashes was observed at all other intersection types. Traffic signals in the open country showed a crash frequency that was twice as high as roundabouts. The researchers affirm that in open country traffic signals should be avoided and roundabouts provide a safe intersection.

Design recommendations for approach geometry at roundabouts on high speed roadways vary from country to country and state to state. NCHRP Report 672, *Roundabouts: An Informational Guide, Second Edition (28)* suggests that there may be some benefit on rural high speed roadways to introduce additional design modifications (longer splitter island or horizontal curvature) to slow drivers in advance of the intersections rather than relying on signing. The treatments suggested for roundabouts with high speed approaches include, visibility or conspicuity of the central island *(28,29)* , outside and inside curbing to define the desired path of the vehicles and subtly encourage additional reduction in speeds with a narrower cross section, splitter islands with a minimum length of 200ft in advance of the yield line, flatter and longer tapers in advance of the splitter islands, and potentially considering the introduction of approach curvature *(26,28,30)*, however approach curvature is not recommended for design in New Zealand *(31)*. Appropriate design of these curves is critical to their effectiveness and not introducing unintended consequences at the intersection (i.e. loss of control crashes with the curvature). There is no research in the US to suggest that one design is safer than the other.

A review of 50 safety audit reports of roundabouts resulted in a summary of key issues at roundabouts in New Zealand *(29)*. Inadequate signing (location, appropriateness, size and quantity) has been noted as the most common problem by safety auditors according to Transfund New Zealand. Poor signing, inadequate or inappropriately located, (relating to rural environments) can lead to confusion for unfamiliar drivers seeking a particular location and affect the ability of the driver to anticipate the intersection. Transfund suggests providing larger warning signs on high speed approaches and/or increasing the number of signs (i.e. one on each side of the road) and installing large advance directional signs.

### *Approach Speed and Speeds as a Surrogate*

The relationship between intersection speed and safety is one that is speculated about often, but little data exists to clearly identify what that relationship might be. The research that is available is clear – speed can influence the likelihood of a crash and the severity of a crash. Hauer *(32)* found that on rural roadways that the larger variation from the median traffic speeds the more likely conflicts will occur. In TRB Special Report 254, *Managing Speed: Review of Current Practice for Setting and Enforcing Speed Limits, (33)* acknowledges that the connection between speed and safety is complex. The report also states the following:

- "The probability of severe injury increases sharply with the impact speed of a vehicle in a collision, reflecting the laws of physics."
- "Speed is also linked to the probability of being in a crash, although the evidence is not as compelling because crashes are complex events that seldom can be attributed to a single factor."

The formula for kinetic energy, shown in Equation 1, provides the evidence to why speed and differential in speed makes a difference - velocity is squared. So when a driver reacts to an impending collision, the vehicle decelerates rapidly until the crash occurs but the occupants of the vehicles continue to move at the speed of the vehicle prior to the crash *(34)* and the risk of injuries and fatalities increases as a function of speed prior to the crash *(35).*

$$KE = \tfrac{1}{2}\,Mass \times Velocity^2 \qquad \textbf{Equation 1}$$

Harder et al. *(36)* performed a before and after simulation study of advance stop line rumble strips at rural intersections in Minnesota. The drivers in the simulator removed their foot from the brake at approximately the same time (~1100 ft) with and without the rumble strips but they applied the brake earlier (550 ft vs. 485 ft) and more often when rumble strips were present. It was theorized that the braking pattern associated with rumble strips is more controlled and might imply safer approaches to intersections, however on the flip side braking earlier may increase incidences of rear end collisions if vehicles are following too closely. This study suggested additional research in this area.

NCHRP Report 613 *Guidelines for Selection of Speed Reduction Treatments at High-Speed Intersections (6,37),* summarizes a before and after study of three speed reduction treatments (rumble strips, peripheral transverse marking, dynamic warning sign) at ten intersections (19 approaches). Results showed that dynamic warning signs reduced the mean speed 1.7 mph, 2.3 mph and 2.8 mph at the following locations, respectively, sign, perception-reaction location (250 ft upstream) and the accident avoidance location; transverse pavement markings reduced overall mean speeds marginally by 0.6 mph; and transverse rumble strips produced statistically significant speed reductions at the perception-reaction location (1.3 mph) and there was no statistical significance at the location of the rumble strips or at the accident avoidance location (100 ft upstream). No documented safety effects were reported as a part of this study.

Although speed studies that have been done at intersections do show safety countermeasures with promise, no treatment can compare to the safety benefits of a roundabout. Roundabouts were recognized in NCHRP Report 613 *(6)* as a highly effective intersection treatment to reduce vehicle speeds at intersections on high speed roadways. NCHRP Report 572 *Roundabouts in the United States (15,38)* documented speed data at 200 ft upstream of the yield line, at the yield line, at the midpoint of the adjacent splitter island and at the exit point of the roundabout and concluded that vehicle speed is a driver's response to the design of the roadway.

Roundabouts, by design, slow all vehicles entering the intersection; however crashes still occur at roundabouts. Reported crashes at roundabouts with high speed approaches tend to be overrepresented by single vehicle crashes (38 percent). A study from the Insurance Institute of Highway Safety *(39)*, reports that speed related issues at roundabouts may result from a lack of advanced signing, insufficient street lighting, wide approach lane widths, lack of conspicuous central island landscaping, and short splitter island lengths. Mandavilli et al.

*(39)* suggest several low costs solutions to encourage speed reduction prior to the roundabout, some include enhanced landscaping, reflective signs on the central island, extension of the splitter island, and enhanced street lighting. Turner and Roozenburg *(24)* report that there is a relationship between accidents, speed, traffic volume and sight distance at roundabouts.

Crashes still remain to be rare and random events and transportation agencies strive to assess risk on their roadways without waiting for a crash to occur. In the absence of crash data, surrogate events to crashes may provide complementary information to decision makers *(14)*. Research identifies traffic conflicts, delay, encroachment, violations, road user behavior, and speed all as crash surrogates *(3,7,10,11)*. Speed is a factor in 31% of all fatal crashes and of those 51% (5,398) are on non-interstate roadways with a posted speed limit of 40 mph or more *(4)*. Specifically related to intersections, Perkins and Thompson *(40)* stated that candidate surrogates for rural non-signalized intersections are traffic volume, approach speed, sight distance and traffic conflicts. Therefore, speed can be a viable crash surrogate.

Specific to roundabouts, Chen et al. *(13)* utilized the speed data collected at roundabouts under the NCHRP Report 572 *(15)* study in an exploratory analysis of safety performance and its relation to speed. The study demonstrated that “it is viable to use speed as a surrogate measure in estimating the safety implications of decisions in designing a roundabout.”

## Data Collection Methodology

Field and observational data were collected at four rural roundabout intersections and two, two-way stop control intersections on rural high speed roadways. Speed data from each of the intersections were used to compare the speed profiles and speed variance of vehicles approaching these intersections. Data were not collected under adverse weather conditions. Most of the data collection was done with one or two people.

## Site Selection

This research was not a funded research project so limited resources were available to collect field data. At the time of data collection there were only approximately nineteen intersections that fit the characteristics for this research. Data collection sites were considered by intersection characteristics (rural, high speed approaches), available before and after crash data, cooperation of agency owning the roadways and proximity to Iowa. These criteria resulted in four candidate roundabouts and included rural New Prague, Minnesota and Paola, Florence and Garnett, Kansas. Additionally, two rural two-way stop controlled intersections emulating the same criteria as the roundabout were selected. The two locations in Iowa were rural Story County and rural Polk County. Table 1 shows a summary of the field locations.

**TABLE 1. Field Data Collection Sites**

| Intersection Type | Location (nearest town) | Roadways | Intersection Approaches | # of Approaches w/ Speed Data |
|---|---|---|---|---|
| **Roundabout** | NE of New Prague, MN | State Highway 13 and County Highway 2 | 4 | 55mph (4) |
|  | North of Paola, KS | State Highway 68 and Old Kansas City Rd. | 5 | 65mph (1)<br>55mph (2) |
|  | West of Florence, KS | US 50 and US 77 | 5 | 65 mph (1)<br>55 mph (1) |
|  | South of Garnett, KS | US 169 and US 59 | 3 | 65 mph (1) |
| **Two-way Stop Control** | NW of Ames, IA (Story County) | County Road R-38 and County Road E-36 | 4 | 55 mph (3) |
|  | SE of Alleman, IA (Polk County) | State Highway 87 and County Road F22 | 4 | 55 mph (4) |

The roundabout sites could be divided into three sub categories, posted speed limit of 65mph with rumble strips, posted speed limit of 55mph with rumble strips and posted speed limit of 55 mph without rumble strips. The two-way stop controlled intersections have posted speed limits of 55 mph. Lighting was present at all the intersections.

## Equipment

Various speed data collection equipment was considered for this research. The equipment used had to be readily available, could be installed and removed by one person, easy to transport in an automobile, reliable and ease in data reduction. TRAX® road tubes (JAMAR Technologies) were available for this research and had recently been calibrated using a radar gun and speed trailer. A total of twelve road tube data recorders were available for use which dictated the number of approaches and number of locations where data could be collected at each intersection. Figure 1 shows the road tubes at the Roundabout Ahead Sign, the series of three rumble strips and the road tubes at 2, 250 ft in Paola, KS.

**FIGURE 1. Photo showing road tubes at 1,500 ft and series of three rumble strips**

## Layouts and Data Collection

Road tube spacing and locations were considered carefully prior to data collection as well as in the field. Specific site conditions dictated the final data collection efforts, excluding approaches where driveway would impact locations the speed data. Speed data were collected on ten approaches at four different roundabouts and seven approaches at two, two-way stop controlled intersections. Locations included 100 ft, 250 ft and 500 ft from the yield/stop line on all approaches as well as at 1,500 ft from the yield line/stop line, typically at the “Roundabout Ahead Sign” warning sign for the roundabouts. The road tubes placed at 500 ft typically corresponded with the location of the Yield Ahead signs. Speeds at 2,500 ft were also collected on three roundabout approaches. The stop controlled intersection had stop ahead signs installed approximately 500 ft from the stop line. Figure 2 shows a typical layout for the data collection of the roundabouts and two-way stop controlled intersection and Table 2 lists distance of the data collection points and the advanced traffic control on the approaches.

**FIGURE 2. Typical intersection approach with traffic control and data collection locations**

## TABLE 2. Distances from Yield Line/Stop Line

| | | Feet from Yield Line | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Location | Approach | Yied Sign | Road Tube | Nose of Splitter Island | Road Tube | Diagrammatic Sign | Road Tube | Yield Ahead Sign | Roundabout Ahead | Road Tube | Rumble Strip 3 | Rumble Strip 2 | Rumble Strip 1 | Road Tube | Speed Limit | Advisory Speed Plate |
| Paola | | | | | | | | | | | | | | | | |
| | EB | 0 | 100 | 165 | 250 | 530 | 500 | 888 | 1429 | 1429 | 1553 | 1677 | 1801 | 2250 | 65 | 15 |
| | NB | 0 | 100 | 250 | 250 | na | 500 | 393 | 738 | 750[a] | 862 | 986 | 1110 | na | 55 | 15 |
| | SB | 0 | 100 | 250 | 250 | na | 500 | 531 | 728 | na | 852 | 976 | 1100 | na | 55 | 15 |
| Garnett | | | | | | | | | | | | | | | | |
| | NB | 0 | 100 | 235 | 250 | 326 | 500 | 576 | 1526 | 1526 | 2068 | 2192 | 2316 | 2750 | 65 | 20 |

| Location | Approach | Yied Sign | Road Tube | Nose of Splitter Island | Road Tube | Yield Ahead Sign | Road Tube | Diagrammatic Sign | Roundabout Ahead | Road Tube | Rumble Strip 3 | Rumble Strip 2 | Rumble Strip 1 | Road Tube | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Florence | | | | | | | | | | | | | | | | |
| | SB | 0 | 100 | 155 | 250 | 410 | 500 | 607 | 1214 | 1214 | 1338 | 1462 | 1586 | 2500 | 55 | 20 |
| | EB | 0 | 100 | 155 | 250 | 558 | 500 | 820 | 1558 | 1558 | 1682 | 1806 | 1930 | na | 65 | 20 |

| Location | Approach | Yied Sign | Road Tube | Nose of Splitter Island | Road Tube | Yield Ahead Sign & Pavement Marking | Road Tube | Diagrammatic Sign | Roundabout Ahead | Road Tube | Rumble Strip 3 | Rumble Strip 2 | Rumble Strip 1 | Road Tube | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| New Prague | | | | | | | | | | | | | | | | |
| | NB | 0 | 100 | 300 | 250 | 440 | 500 | 840 | 1290 | 1290 | na | na | na | na | 55 | 20 |
| | SB | 0 | 100 | 300 | 250 | 500 | 500 | 975 | 1475 | 1475 | na | na | na | na | 55 | 20 |
| | EB | 0 | 100 | 200 | 250 | 450 | 500 | 900 | 1350 | 1350 | na | na | na | na | 55 | 20 |
| | WB | 0 | 100 | 200 | 250 | 460 | 500 | 910 | 1360 | na | na | na | na | na | 55 | 20 |

| | Approach | Stop Sign | Road Tube | Road Tube | Stop Ahead | Road Tube | Road Tube |
|---|---|---|---|---|---|---|---|
| Story County | | | | | | | |
| | WB | 0 | 100 | 250 | 500 | 500 | 1500 |
| | NB | na | 100 | 250 | na | 500 | na |
| | SB | na | 100 | 250 | na | 500 | na |
| Polk County | | | | | | | |
| | NB | 0 | 100 | 250 | 500 | 500 | 1500 |
| | SB | 0 | 100 | 250 | 500 | 500 | 1500 |
| | EB | na | 100 | 250 | na | 500 | na |
| | WB | na | 100 | 250 | na | 500 | na |

[a] - The fourth road tube was placed at the Roundbaout Ahead Signs. On this approach that distance was 750 ft rather than 1500 ft in advance of the yield line.

### *Speed Data*

With a limited number of roundabouts to study on rural roadways it was important to gather as many data points as possible on each of the approaches. A minimum of four hours and a maximum of eight hours of data were collected at the roundabout approaches and an average of eighteen hours of data was collected at the two-way stop controlled approaches (due to the closer proximity of the intersection to the data collection team.)

The speed data collected on the through approaches at the two-way stop controlled intersections was collected in order to verify the suspected large speed differentials between turning and through traffic as well as the speed differentials between the major and minor approaches.

### *Crash Data*

The crash data used for the roundabouts was obtained as a part of the safety analysis that was done in for Chapters 4 and 5. The Iowa Traffic Safety Data Service (ITSDS) provided crash data history for the two Iowa intersections.

## Data Reduction

The speed data for the road tubes was exported using the TRAX® software. All speed data that were collected during the road tube installation and removal timeframes was deleted from the data set, as well as all erroneous records (i.e. speeds equal to 0 mph, repeat records) were excluded from the data set. Over 30,700 speed data points (speeds) were recorded.

## Data Analysis and Results

The analysis done was to test the statistical significance between approach speeds at roundabouts and two-way stop controlled intersections. Two comparative studies were made for 1) six roundabout approaches with rumble strips and four roundabout approaches without rumble strips, and 2) the four roundabout approaches without rumble strips and three stop controlled approaches at two-way stop controlled intersections. Additionally, the variance in speeds for each of the intersection types was evaluated.

## Methodology

Each data set was determined to be normally distributed and both speed data comparisons involved two sets of data with unequal sample sizes. To test the statistical significance of the means, the test statistic (t-test) is an appropriate choice for this data (*37,41)*, as shown in Equation 2. The computed value of "t" was compared to the critical value of " t" for the sample size based on the specified level of significance. All statistical tests were performed at the 95 percent confidence level.

$$t = \frac{\overline{X_1} - \overline{X_2}}{\sqrt{\frac{s_1^2}{N_1} + \frac{s_2^2}{N_2}}}$$

**Equation 2**

Where:

t = statistic of the t distribution

$X_1$ = mean of the first sample

$X_2$ = mean of the second sample

$s_1$ = standard deviation of the first sample

$s_2$ = standard deviation of the second sample

$N_1$ = number of observations in the first sample

$N_2$ = number of observations in the second sample

## Speed Data

Speed data from the through approaches on the two-way stop controlled intersections was reviewed but not further analyzed as a part of this study because of the bi-modal distribution. This resulted because of vehicles slowing to turn or through vehicles slowing for turning vehicles decelerating or accelerating on the major roadway. Table 3 shows these mean speeds. Documenting these findings is important here as the operations and speed data on the approaches to roundabouts is expected to be significantly different because *all* vehicles slow at roundabouts.

Speed profiles were created for each approach based on the speed data collection points. As is shown in Figure 3, the speed profiles for the roundabouts with rumble strips (solid lines) show greater variation in mean speeds, whereas the roundabouts without rumble strips and the stop controlled approaches have a smaller variance in mean speeds.

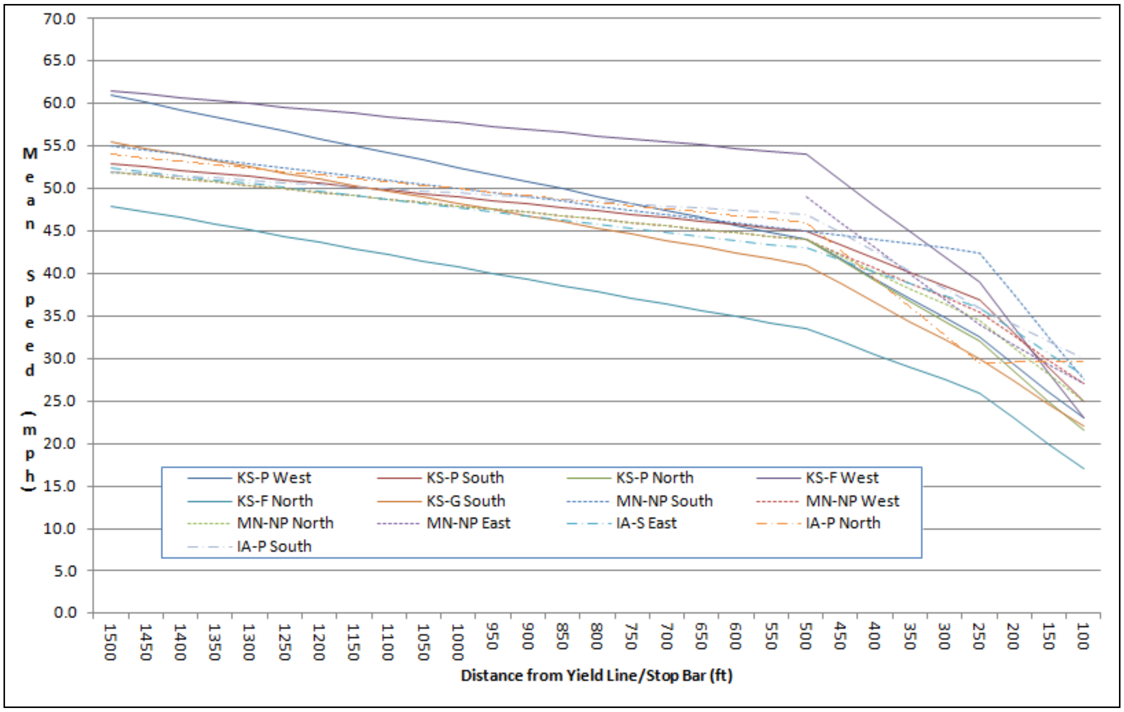

**FIGURE 3. Speed profiles**

The mean and 85th percentile speeds are shown in Table 3 by approach and the descriptive statistics by intersection types are shown in Table 4. Based on the descriptive statistics, the mean speeds do not indicate large discrepancies between the intersection categories, however the sample variances does show a considerable difference on the approaches with rumble strips.

## TABLE 3. Mean and 85th Percentile Speeds for Individual Approaches

| | | | Mean Speeds (mph) | | | | 85th Percentile Speed (mph) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Treatment** | **Number of Intersections** | **Approach** | **100 ft** | **250 ft** | **500 ft** | **1500 ft** | **100 ft** | **250 ft** | **500 ft** | **1500 ft** |
| **Roundabout w/ Rumble Strips** | | | | | | | | | | |
| | KS-P | W | 23 | 32.5 | 44 | 61 | 28 | 38.5 | 50 | 65.5 |
| | | S | 25 | 37 | 45 | 53 | 29 | 42 | 50.5 | 58 |
| | | N | 21.5 | 32 | 44 | | 25.5 | 36 | 49.5 | |
| | KS-G | S | 22 | 30 | 41 | 55.5 | 28 | 36.5 | 47.5 | 61 |
| | KS-F | N | 17 | 26 | 33.5 | 48 | 22 | 32 | 40 | 55 |
| | | W | 23 | 39 | 54 | 61.5 | 28 | 46 | 62 | 67.5 |
| **Roundbaout w/o Rumble Strips** | | | | | | | | | | |
| | MN-NP | N | 25 | 35.5 | 44 | 52 | 28.5 | 41.5 | 49 | 56 |
| | | S | 27.5 | 34.5 | 45 | 55 | 31.5 | 39 | 51.5 | 60 |
| | | E | 27 | 34 | 49 | | 30.5 | 39 | 54 | |
| | | W | 27 | 38 | 44 | 52 | 31 | 42 | 49 | 56 |
| **TWSC** | | | | | | | | | | |
| | IA-S | E | 28 | 36 | 43 | 52.5 | 30.5 | 39.5 | 47 | 57 |
| | | N | 24.5 | 34 | 41 | | 28 | 38.5 | 47 | |
| | | N-Thru | 59 | 58.5 | 59.5 | | 62.5 | 62.5 | 63.5 | |
| | | S | 28 | 35 | 57 | | 31.5 | 39.5 | 63.5 | |
| | | S-Thru | 60.5 | 56 | | | 66 | 60 | | |
| | IA-P | N | 29.5 | 29.5 | 46 | 54 | 32.5 | 32.5 | 51 | 59.5 |
| | | S | 30 | 36 | 47 | 52 | 32 | 39.5 | 51.5 | 57 |
| | | E | 30.5 | 38 | 41 | | 34.5 | 42 | 45 | |
| | | E-Thru | 60 | 54.5 | 55 | | 64.5 | 58.5 | 59 | |
| | | W | 31 | 43.5 | 43 | | 36 | 48 | 48 | |
| | | W-Thru | 55 | 64.5 | 58 | | 59.5 | 69.5 | 62 | |

**TABLE 4. Descriptive Statistics**

| | | | | | mph | | | |
|---|---|---|---|---|---|---|---|---|
| **Treatment** | **Number of Intersections** | **Approaches** | **Road Tube Location** | **Number of Measurements** | **Mean** | **Standard Deviation** | **Sample Variance** | **Speed Range** |
| **Roundabout w/ Rumble Strips** | 3 | | | | | | | |
| | | 6 | 100 ft | 3234 | 22.1 | 6.0 | 35.4 | 4 to 44 |
| | | 6 | 250 ft | 3225 | 32.2 | 7.5 | 55.6 | 8 to 62 |
| | | 6 | 500 ft | 3267 | 42.4 | 8.5 | 71.7 | 9 to 74 |
| | | 2 | 1500 ft-55 | 1208 | 50.4 | 7.0 | 47.3 | 17 to 69 |
| | | 1 | 2500 ft-55 | 643 | 49.2 | 5.8 | 29.7 | 20 to 64 |
| | | | | | | | | |
| | | 3 | 1500 ft-65 | 1652 | 57.9 | 6.9 | 48.7 | 29 to 78 |
| | | 2 | 2500 ft-65 | 1405 | 61.0 | 5.4 | 34.1 | 27 to 91 |
| **Roundbaout w/o Rumble Strips** | 1 | | | | | | | |
| | | 4 | 100 ft | 1847 | 26.4 | 4.4 | 19.3 | 10 to 44 |
| | | 4 | 250 ft | 1875 | 35.5 | 5.7 | 32.8 | 8 to 53 |
| | | 4 | 500 ft | 1883 | 45.3 | 6.6 | 43.5 | 14 to 64 |
| | | 3 | 1500 ft | 959 | 53.9 | 5.9 | 35.2 | 16 to 70 |
| **Stop Controlled** | 2 | | | | | | | |
| | | 3 | 100 ft | 2224 | 28.9 | 3.5 | 12.4 | 12 to 51 |
| | | 3 | 250 ft | 2529 | 34.8 | 4.9 | 23.7 | 12 to 50 |
| | | 3 | 500 ft | 2507 | 45.0 | 5.8 | 34.0 | 9 to 77 |
| | | 3 | 1500 ft | 2264 | 52.5 | 6.5 | 42.5 | 15 to 76 |

Figures 4 and 5 further illustrate the variance in the speeds for the intersections at the various data collection locations. Looking at the speed data graphically it is evident that the intersections are operating quite differently. At every data collection point along the approach, the stop controlled approaches have a narrower distribution, less variance in speed, and the roundabout approaches with the rumble strips show a greater variance in speeds but a lower mean speed. At 250 ft and 500 ft the roundabout approaches without rumble strips and the stop controlled approaches have more similar distributions but still the mean speeds are

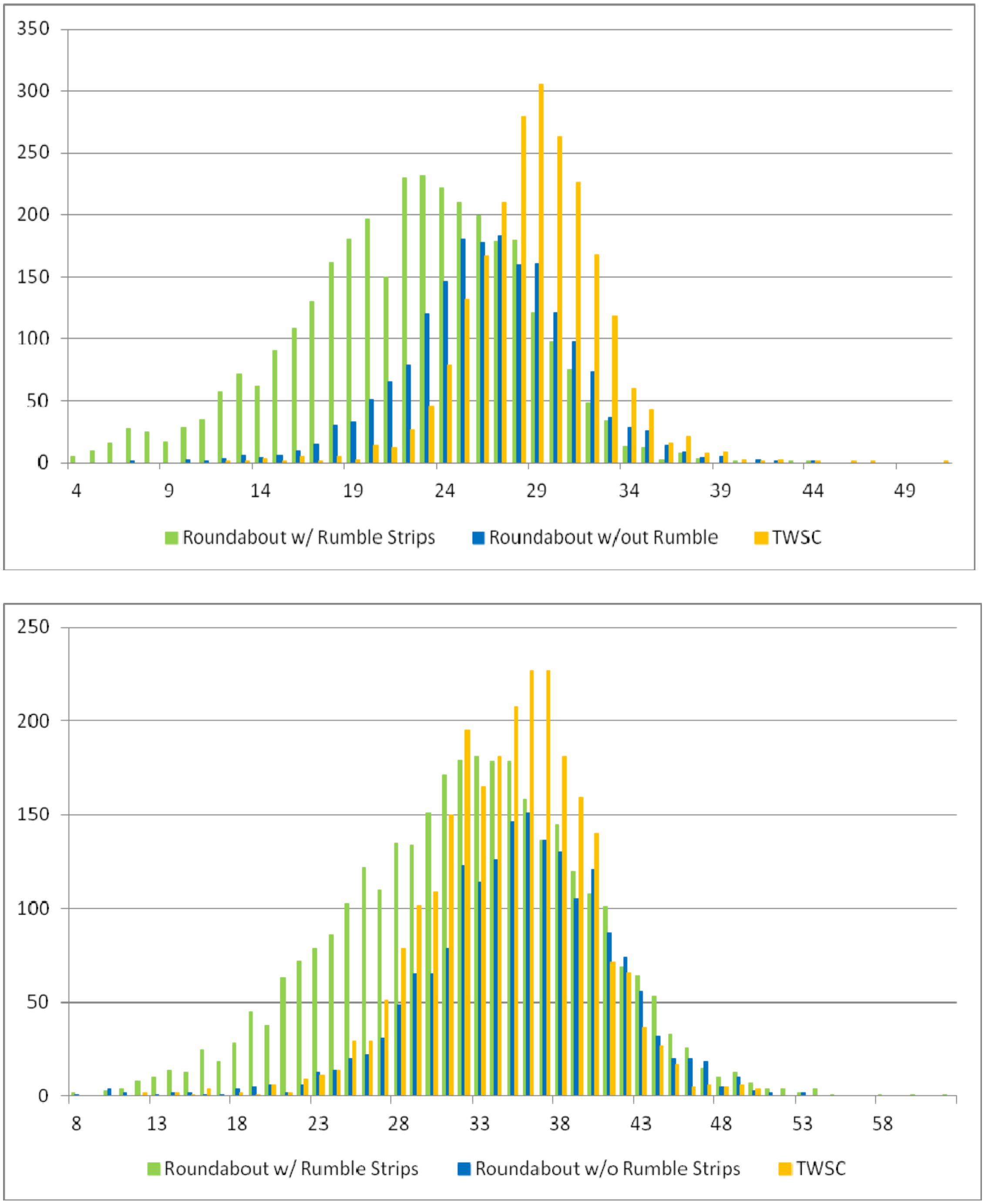

**FIGURE 4. Speed data at 100 ft (top) and 250 ft (bottom) from yield/stop line**

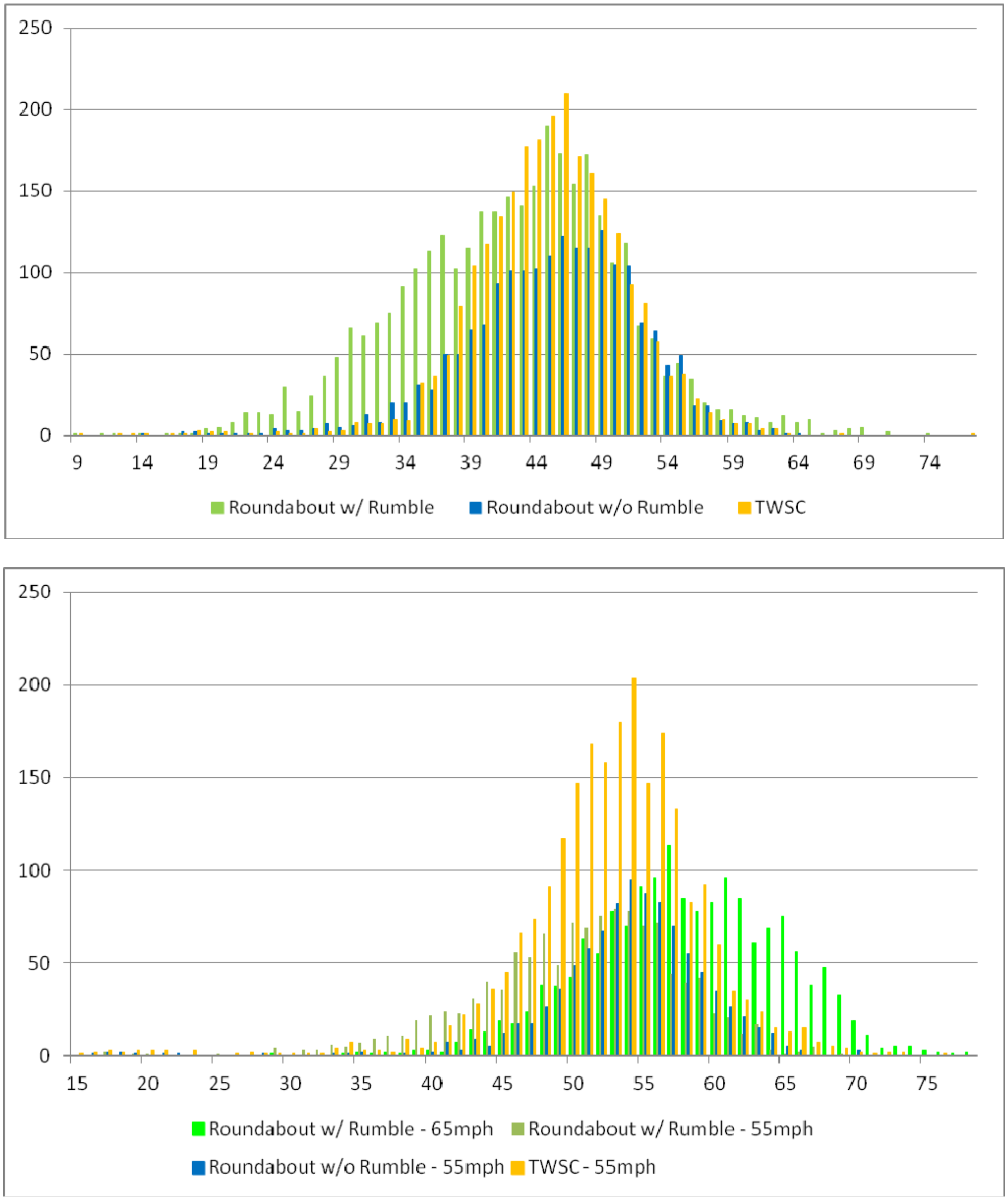

**FIGURE 5. Speed data at 500 ft (top) and 1500* ft (bottom) from yield/stop line**

Not only is the sample variance an interesting finding, but also the number of vehicles that would likely not be able to stop and the yield line or stop bar. Considering the accident-avoidance distances documented in Ray et al. *(37)*, at 100 ft from the yield line/stop bar a vehicle would need to be driving 32 mph or less to skid and stop short of a collision at the intersection. At the roundabouts with rumble strips, only 2.3 % (seventy-four) of the vehicles speeds exceeded 32 mph; at the roundabouts without rumble strips 6.8 % (125) of the vehicles exceeded the 32 mph; and at the stop controlled approaches, 12.5 % (279) of the vehicles would not be likely to avoid a crash. More of a concern here is at the stop controlled approaches, as it is possible that the vehicles at the roundabout that exceed the crash avoidance distances could have observed that the circulating roadway is clear and they can enter the roundabout at the advisory speeds (15 or 20 mph in this case).

Additionally, the number of vehicles exceeding the speed limit at free flow speeds, approximately 1,500 ft from the intersection (but after the rumble strips, if applicable) was inconsistent. On the roundabout approaches with rumble strips, 14 percent of vehicles were exceeding the 65 mph speed limit but only 2% were more than 5 mph over and on the 55 mph approaches 23 % were over the speed limit and 5 % were more than 5 mph over. However, at the roundabout approaches without rumble strips 39 % of vehicles exceeded the 55 mph speed limit and 9% over more than 5 mph over and the two-way stop controlled intersections were similar with 31 % over the posted 55 mph speed limit and 7% exceeding 5 mph over.

The test of statistical significance for the mean speeds on the roundabout approaches with and without rumbles strips shows statistically significant difference in mean speeds at 100 ft, 250 ft, 500 ft and 1,500 ft from the intersection at the 95 percent confidence level. Tables 5 and 6 show the differences in speeds and P-values. The only distance that was not statistically significant comparing the roundabouts without rumble strips and stop controlled approaches was at 500 ft.

**TABLE 5. Test of Statistical Significance for Roundabouts with and without Rumble Strips**

| | Mean Speed (mph) | | | | |
|---|---|---|---|---|---|
| Distance from Yield Line | Roundabout w/ Rumble Strips | Roundabout w/o Rumble Strips | Difference | P-Value | Significant |
| 100 ft | 22.1 | 26.4 | 4.3 | 0 | Yes |
| 250 ft | 32.2 | 35.5 | 3.3 | 0 | Yes |
| 500 ft | 42.4 | 45.3 | 2.9 | 0 | Yes |
| 1500 ft | 50.4 | 53.9 | 3.4 | 0 | Yes |

**TABLE 6. Test of Statistical Significance for Roundabouts and Stop Controlled Approaches**

| | Mean Speed (mph) | | | | |
|---|---|---|---|---|---|
| Distance from Yield Line/Stop Bar | Roundabout w/o Rumble Strips | Stop Controlled | Difference | P-Value | Significant |
| 100 ft | 26.4 | 28.9 | 2.5 | 0 | Yes |
| 250 ft | 35.5 | 34.8 | -0.7 | 0 | Yes |
| 500 ft | 45.3 | 45.0 | -0.3 | 0.1257 | No |
| 1500 ft | 53.9 | 52.6 | -1.3 | 0 | Yes |

## Crash Data

It has already been discussed that roundabouts change the intersection environment for drivers so it only makes sense that the number and types of crashes that occur at roundabout are different. For the roundabout intersections, before and after crash data was reviewed and crash was also obtained for the two-way stop controlled intersections. Considering the descriptive statistics for these intersections where speed data were collected, it is evident that the conversion from two-way stop controlled intersections to roundabouts radically reduced the total number of crashes as well as the number of injury crashes.

At these four roundabouts only twenty-one (21) total crashes and four (4) injury crashes have occurred in the ten data years and . Before the roundabouts 139 total crashes and 76 injury crashes occurred during the 29 data years. Considering the crashes that have occurred at the roundabouts since installation it is difficult to find a pattern as so few crashes occur after a roundabout is constructed. Four of the twenty-one crashes were speed related, two of those being injury crashes. The other two injury crashes were failure to yield right of way. Seven of the crashes were single vehicle crashes.

Nine years of crash data were available for the two, two-way stop controlled intersections in Iowa. Seventeen crashes occurred at those intersections during that time, including five injury crashes. Nine of those crashes were either “ran stop sign” or “failure to yield right of way” and two of those were injury (including a fatal) crashes.

## Conclusions and Discussion

The analysis of speed data shows that there is a statistically significant difference in the speed selection for drivers when approaching different types of intersections and associated traffic control. The difference in mean speeds varied by distance as the driver approached the intersections. When comparing the roundabout (without rumble strips) and the stop controlled approaches, at 1,500 ft in advance of the intersection, drivers approaching a roundabout were on average traveling 1.3 mph higher than when approaching a stop controlled intersection and at 250 ft this difference was only 0.7 mph. At 100 ft in advance, which is by far a more critical zone for compliance, vehicle approaches the roundabout were found to be traveling on average 2.5 mph lower. Drivers approaching roundabouts were found to exhibit similar mean speeds and similar speed distributions at 250 ft, 500 ft and 1,500 ft. These small, yet statistically significant differences in mean speed indicates that, in fact, drivers are selecting approach speeds to roundabouts similar to that of a more familiar stop controlled intersection. However, between 250 ft and the yield line/stop bar, a distance from the intersection where the driver may or may not be able to bring their vehicle to a complete stop, the mean speed is higher (2.5 mph) and 12.5 % of the drivers exceeded the 32 mph speed at which a driver could potentially avoid a crash.

Albeit the differences in mean speeds are statistically significant, the speeds difference between intersection types is low (within 1.3 mph). Even with advanced traffic control signing (Roundabout Ahead sign, Yield Ahead Sign, and a Diagrammatic sign in some cases) at the roundabout, approach speeds were found to be very similar to a stop controlled approach until you get to within 100 ft of the intersection. Drivers on a roundabout approach are already under the influence of the splitter island, outside curb and alignment deflection and these factors could be contributing to lower mean speeds, which are 2.5 mph less than at a stop controlled approach. A higher percentage (6.8 vs. 12.5 percent) of drivers at the stop controlled intersections appear to be at riskier speeds within 100 ft of the intersection.

A statistically significant difference was also realized for the mean speeds (2.9 to 4.3 mph lower) on the approaches to a roundabout with rumble strips compared to roundabouts without. With the advanced traffic control (signing) and lighting being nearly identical, the only notable difference between these approaches was the presence of rumble strips at the Kansas roundabouts. The data shows that rumble strips initiate lower speeds, earlier (further from the intersection) and is consistent with the Minnesota simulation study on rumble strips *(36)*. The rumble strips do seem to introduce noticeable variability in the speeds at all data collection points. More specifically, the rumble strips seem to change driver behavior (i.e. slowing down sooner) between the rumble strips and 500 ft in advance of the roundabout. Although slower is viewed as safer, and in the case here the rumble strips seem to provide that effect, the increased speed variability may offset those benefits by introducing the potential for rear end crashes.

Speed and variation in speed are certainly good candidates as crash surrogates but because roundabouts change the driving environment and driver must slow before entering the intersection it seems as if speed/speed variation data might need to be coupled with observing if those speeds cause erratic moves on the approach to a roundabout that may very well be a potential crash situation that could be avoided due to the already evident slower speeds.

Although roundabouts significantly reduce the number of property damage and injury crashes on rural high speed roadways, compared to a two-way stop controlled intersections, there is not enough crash data at roundabouts currently (that was why they were constructed in the first place) to isolate the effects of the rumble strips in advance of roundabouts and whether or not they provide additional safety benefits. It is however evident that rumble strips change driver's behavior in advance of roundabouts in this study.

It is getting more difficult to find reasons not to implement roundabouts especially on facilities with higher risk (i.e. two lane rural roadways). Roundabouts change how drivers approach and navigate the intersection, because they physically change the geometry of an intersection approach and how vehicles interact with each other. As documented in this study, roundabouts also reduce vehicle approach speed within the critical decision area (within 100 ft) of the intersection.

Rural intersections with a poor safety history are prime candidates for a roundabout. Investing in an intersection alternative that lowers speeds and significantly reduces the risk of someone in your community getting injured is an intersection alternative worth constructing. Roundabouts prevent high speed angle crashes that results from drivers running stop signs and red lights.

The implementation rate of roundabouts on high speed rural approaches is significantly higher in the last three years due to several states who continue to aggressively construct roundabouts in rural locations. Numerous other states are also quickly realizing the considerable safety benefits of rural roundabouts on high speed roadways and are including roundabouts as viable alternative in the project development process. There are few intersection safety countermeasures that deliver a high a safety yield than as a roundabout. Roundabouts on rural high speed roadways are saving lives.

## Limitations and Future Research

Limited funds were available for this research and the number of rural roundabouts was also confined to less than twenty at the time of data collection. However, this was the first speed data set documented for rural roundabouts with high speed approaches that could be supplemented with additional data at similar locations to help understand how different traffic control in roundabout approaches effect speeds . Additionally, it would be of interest to isolate the speeds for different vehicle types at the Kansas because of a higher than average truck volume.

## Acknowledgements

Dennis Kroeger was a critical partner in the data collection efforts for this research. Dennis passed away prematurely in September 2009.

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# CHAPTER 7. GENERAL CONCLUSIONS

## Discussion of Results

With nearly 3,000 fatalities and tens of thousands more injury crashes at rural intersections annually, safer intersections in these environments are a necessity. Roundabouts are a proven safety countermeasure. By design, roundabouts command a change in driver behavior – slower speeds for all traffic. This research expanded the data available for study and results show that rural roundabouts with high speed approaches significantly reduced total crashes by 62 to 67% and injury crashes by 85 to 88 % at nineteen rural roundabouts. Moreover, the number of angle crashes, which tend to have a higher likelihood of causing injuries at high speeds, were reduced by 83%, also a statistically significant reduction.

The approach speed data analysis proved that drivers are able to slow down in advance of roundabouts on rural roadways. Even more noteworthy, was that the mean speeds at 100 ft from the yield line were 2.5 mph lower than mean speeds at 100 ft from the stop bar at stop controlled approaches. This difference was statistically significant at the 95 percent level and indicates that drivers are able to take the cues from the advanced traffic control and approach geometry to adjust their speeds before entering the roundabout.

The comparison between the roundabout approaches with and without rumble strips showed mean speeds 4.3 mph and 3.3 mph lower at 100 ft and 250 ft from the yield line, respectively, for the approaches with rumble strips; however, the variation in speeds increased with the introduction of rumble strips. There is not enough crash data at these intersections – which is what the owning agencies were striving for when constructing the roundabouts - to determine if the variation in speeds has an effect on crash experience.

Rural intersections with a poor safety history are prime candidates for roundabouts, primarily if those crashes have produced injuries. In addition to the safety and approach speed statistical analyses presented as a part of this research, a crash prediction model specifically for rural roundabouts on high speed roadways is presented. Crash prediction models can help agencies assess the potential safety benefits (reduced crashes) gained by safety countermeasures. These models supplement the models presented in NCHRP Report 572 and the crash modification factors for roundabouts in the Highway Safety Manual.

The results of this research support decision-making to invest in an intersection alternative that lowers speeds and significantly reduces the risk of injury crashes. Roundabouts eradicate the risk of drivers running stop signs and red lights. The current roundabout safety research demonstrates that roundabouts are reducing fatal and injury crashes in all roadway environments in the United States. Furthermore, the research presented here provides evidence that rural roundabouts on high speed roadways are reducing intersection injury crash experiences unlike any other intersection countermeasure.

Roundabouts save lives.

## Limitations of Research

Limited resources were available for this research. The number of rural roundabouts on high speed roadways was minimal at the time of this research but this data set more than doubled the rural roundabouts on high speed roadways evaluated under previous research and provides the groundwork for research in this area.

## Recommendations for Future Research

Just as the *NCHRP Report 572 Roundabouts in the United States* increased the data available for study of roundabouts from twenty-three to fifty-five, this safety research expanded the data for rural roundabout from nine to nineteen. It is recommended that as the number of rural roundabouts increase, the crash prediction models be adjusted and calibrated, as needed.

The data collected for this research can be expanded and evaluated in different ways, including determining if there are distinct patterns with the types of crashes that do occur at rural roundabouts (not enough crash data yet – which is a good problem to have) as well as parsing

# APPENDIX A. CANDIDATE INTERSECTIONS

| | State | City | County/ Region | Intersection |
|---|---|---|---|---|
| 1 | Ontario, Canada | Ancaster | Hamilton | Hamilton Dr/Wilson Street/Meadowbrook Dr (Hwy 403) |
| 2 | Quebec, Canada | Chambly | Montreal | Frchette Blvd/Anne-Le-Seigneur Blvd |
| 3 | Ontario, Canada | Cambridge | Waterloo | Townline rd/Can-Amera Pkwy |
| 4 | Colorado | Eagle | Eagle | SH-6/I-70 spur/Eby Creek Rd |
| 5 | Connecticut | Killingworth | Middlesex | Rte 80/Rte 81 |
| 6 | Kansas | Paola | Miami | K-68/old Kansas City Rd/Hedge Lane |
| 7 | Kansas | Paola | Miami | K-68/old Kansas City Rd/Hedge Lane |
| 8 | Kansas | Florence | Marion | US-50 & US-77 |
| 9 | Maryland | Leeds | Cecil | MD 213/Leeds Rd/Elk Mills Rd (Lanzi Circle) |
| 10 | Maryland | Jarrettsville/North Harford | Harford | MD24/MD165 |
| 11 | Maryland | Lothian | Anne Arundel | MD 2/MD 408/MD 422 |
| 12 | Maryland | Cearfoss/Hagerstown | Washington | MD 63/MD58/Cearfoss Pike |
| 13 | Maryland | Federalsburg | Caroline | MD 307/MD 313/MD 318 |
| 14 | Maryland | Frederick | Frederick | MD 80/Sugarloaf Pkwy |
| 15 | Maryland | Lisbon | Howard | MD 94/MD 144 |
| 16 | Maryland | Lisbon | Howard | MD 94/Old Fredrick Road |
| 17 | Maryland | Millington | Kent | US 301 NB Ramps/MD 291 |
| 18 | Maryland | Millington | Kent | US 301 SB Ramps/MD 291 |
| 19 | Maryland | Rising Sun | Cecil | MD 273/MD 276 |
| 20 | Maryland | Rosemont | Frederick | MD 17/MD 180 |
| 21 | Maryland | Taneytown | Carroll | MD 140/MD 832 |
| 22 | Michigan | Sterling Heights | Macomb | M-53 Freeway/18 1/2 Mile Rd |
| 23 | Minnesota | New Prague | Scott | SH 13/CR 2 |
| 24 | Nevada | Carson City | Carson City | 5th St/Edmonds |
| 25 | New York | Kingston | Ulster | I-587/Rt 28/I-87/Washington Ave |
| 26 | Oregon | Verboort | Washington | Cornelius-Schefflin Rd/Verboot rd |
| 27 | Oregon | Verboort | Washington | Martin-Marsh Rd/Verboort rd |
| 28 | Washington | Duvall | King | State Route 203/NE 124th St |
| 29 | Washington | Spokane | Spokane | SR206/Mt. Spokane park Drive/Bruce Road |

# APPENDIX B. FINAL LIST OF INTERSECTIONS

| | State | City/Town | County | Intersection | Roundabout installation year | Legs | Posted Approach Speed Limit (Max) | Average Daily Entering Volume Before |
|---|---|---|---|---|---|---|---|---|
| 1 | Maryland[1] | Cearfoss/ Hagerstown | Washington | MD 63/MD58/Cearfoss Pike | 1995 | 4 | 50 mph | 6,974 |
| 2 | Washington[2] | Duvall | King | SR 203/Novelty Hill Rd | 2004 | 4 | 50 mph | 11,500 |
| 3 | Maryland[1] | Federalsburg | Caroline | MD 307/MD 313/MD 318 | 1998 | 4 | 50 mph | 6,587 |
| 4 | Kansas[3] | Florence | Marion | US 50/US 77 | 2006 | 5 | 65 mph | 4,848 |
| 5 | Kansas[3] | Garnett | Anderson | US 169/ K- 59 | 2006 | 3 | 65 mph | 5,086 |
| 6 | Wisconsin[6] | Kaukauna | Outagamie | STH 55/CTH KK | 2006 | 4 | 55 mph | 9,000 |
| 7 | Maryland[1] | Leeds | Cecil | MD 213/Leeds Rd/Elk Mills Rd | 1995 | 4 | 40 mph | 8,270 |
| 8 | Maryland[1] | Lisbon | Howard | MD 94/MD 144 | 1993 | 4 | 45 mph | 7,450 |
| 9 | Maryland[1] | Lisbon | Howard | MD 94/Old Fredrick Road | 1998 | 4 | 45 mph | 8,504 |
| 10 | Maryland[1] | Lothian | Anne Arundel | MD 2/MD 408/MD 422 | 1995 | 4 | 50 mph | 13,808 |
| 11 | Minnesota[4] | New Prague | Scott | TH 13/CR 2 | 2005 | 4 | 55 mph | 6,700 |
| 12 | Maryland[1] | North Harford/ Jarretsville | Harford | MD24/MD165 | 2000 | 4 | 55 mph | 8,058 |
| 13 | Kansas[3] | Paola | Miami | K-68/old Kansas City Rd/Hedge Lane | 2001 | 5 | 65 mph | 6,260 |
| 14 | Maryland[1] | Rising Sun | Cecil | MD 273/MD 276 | 2002 | 4 | 45 mph | 15,767 |
| 15 | Maryland[1] | Rosemont | Frederick | MD 17/MD 180 | 2000 | 4 | 50 mph | 13,467 |
| 16 | Wisconsin[6] | Sheboygan Falls | Sheboygan | STH 32/STH 28 | 2006 | 4 | 55 mph | 8,150 |
| 17 | Washington[2] | Spokane | Spokane | SR 206/ Bruce Rd | 2005 | 4 | 50 mph | 10,200 |
| 18 | Oregon[5] | Verboort | Washington | Verboort Rd/Martin/Marsh | 2004 | 4 | 45 mph | 9,253 |
| 19 | Oregon[5] | Verboort | Washington | Verboort Rd/Corneilius Schefflin | 2004 | 3 | 45 mph | 10,980 |

[1] Maryland State Highway Administration, Office of Traffic and Safety, 2007 [7]

[2] Washington DOT, 2008 [15]

[3] Kansas Department of Transportation, Office of Chief Counsel, 2008 [16]

[4] Minnesota Department of Transportation, Office of Traffic and Safety, 2008 [17]

[5] Washington County, Oregon, 2008 [18]

[6] Wisconsin Department of Tranportation, 2008

# APPENDIX C. BEFORE AND AFTER AERIALS AND PHOTOS OF SELECT INTERSECTIONS

Florence, KS (Photo Source: © 2011 Isebrands)

Rural Garnett, KS  (Photo Source: © 2011 Isebrands)

Rural New Prague, MN  (Photo Source: © 2011 Isebrands)

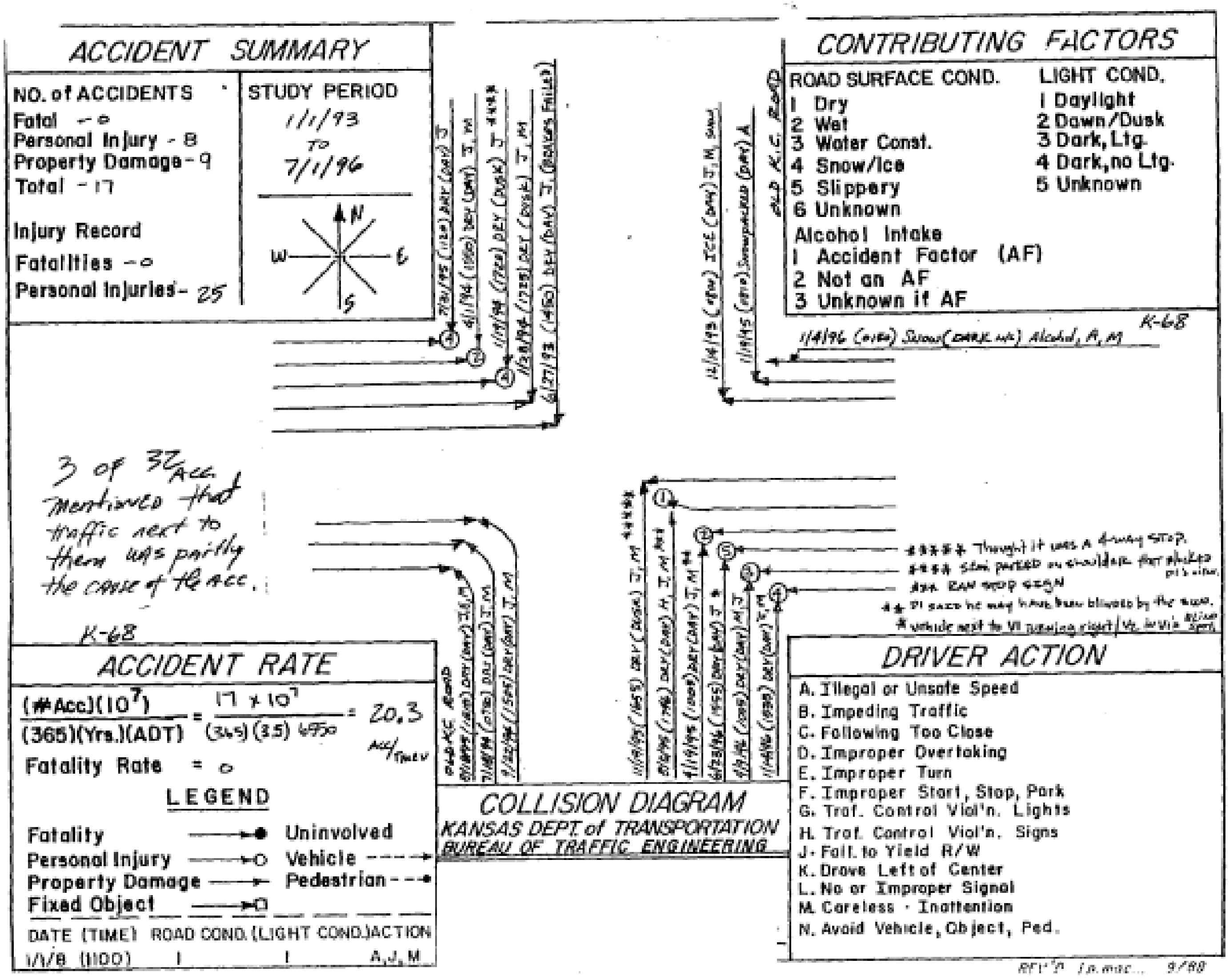
| **Before** | **After** |
|---|---|
|  |  |
| Florence, KS (Image Source: © 2011 Google) | |
|  |  |
| Rural Paola, KS (Image Source: US Geological Survey, © 2011 Google – left; © 2011 Google) | |
|  |  |
| Rural Garnett, KS (Image Source: © 2011 Google) | |

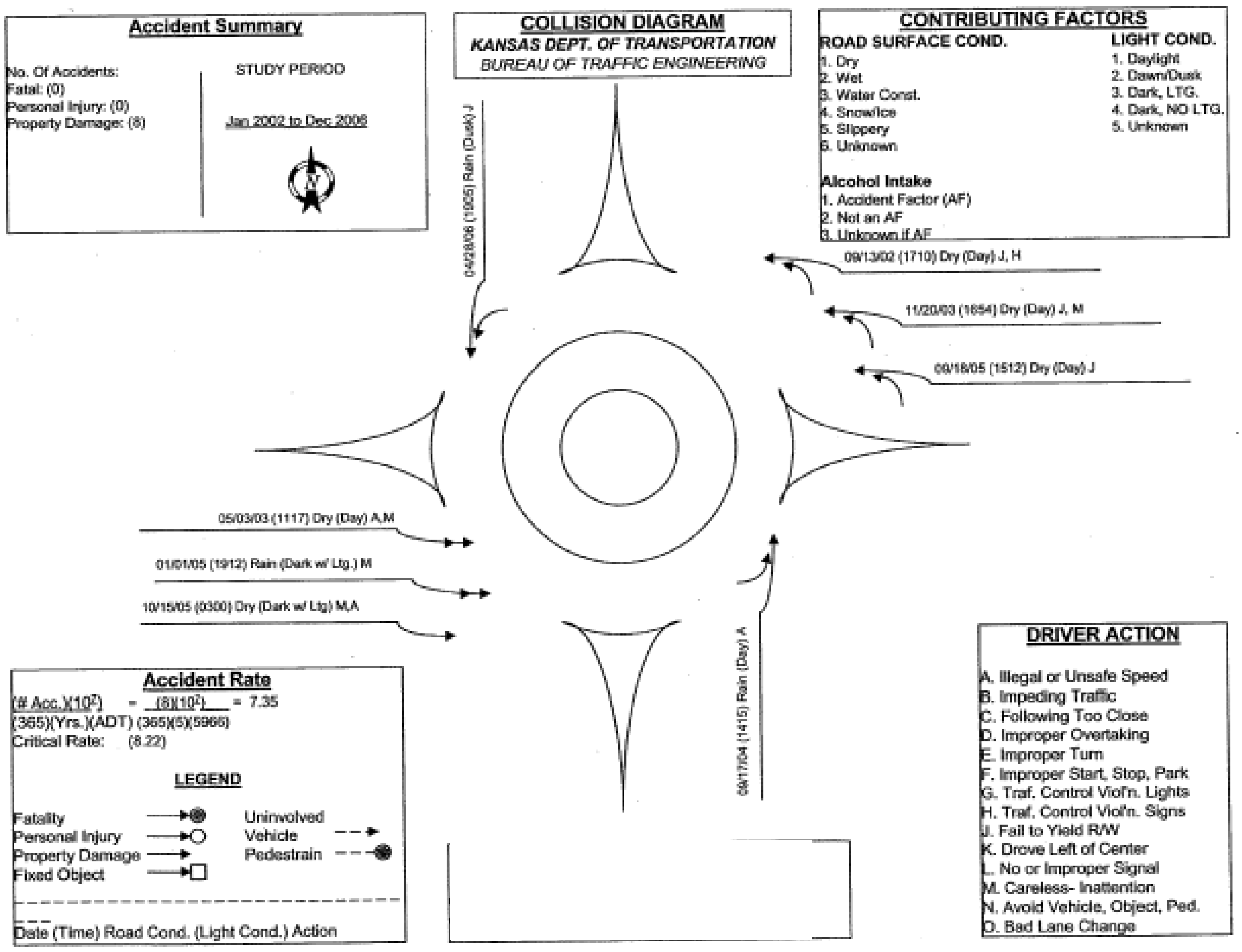
Rural Lothian, MD (Image Source: US Geological Survey, © 2011 Google – left; © 2011 Google – right )

Rural Duvall, WA (Image Source: 2007 Europa Technologies, Image © 2007 DigitalGlobe via Google Earth - left; © 2011 Google - right)

Rising Sun, MD (Image Source: US Geological Survey via Google Earth – left;© 2011 Google - right)

# APPENDIX D. CRASH DIAGRAM EXAMPLES





**Accident Summary**

No. Of Accidents:
Fatal: (0)
Personal Injury: (0)
Property Damage: (8)

STUDY PERIOD

Jan 2002 to Dec 2006

**COLLISION DIAGRAM**
***KANSAS DEPT. OF TRANSPORTATION***
*BUREAU OF TRAFFIC ENGINEERING*

**CONTRIBUTING FACTORS**

**ROAD SURFACE COND.**
1. Dry
2. Wet
3. Water Const.
4. Snow/Ice
5. Slippery
6. Unknown

**LIGHT COND.**
1. Daylight
2. Dawn/Dusk
3. Dark, LTG.
4. Dark, NO LTG.
5. Unknown

**Alcohol Intake**
1. Accident Factor (AF)
2. Not an AF
3. Unkown if AF

**Accident Rate**

$$\frac{(\#\text{ Acc.})(10^2)}{(365)(\text{Yrs.})(\text{ADT})} = \frac{(8)(10^2)}{(365)(5)(5966)} = 7.35$$

Critical Rate: (8.22)

**LEGEND**

| | | | |
|---|---|---|---|
| Fatality | ——▶● | Uninvolved | |
| Personal Injury | ——▶○ | Vehicle | – – ▶ |
| Property Damage | ——▶ | Pedestrain | – – ● |
| Fixed Object | ——▶□ | | |

Date (Time) Road Cond. (Light Cond.) Action

**DRIVER ACTION**

A. Illegal or Unsafe Speed
B. Impeding Traffic
C. Following Too Close
D. Improper Overtaking
E. Improper Turn
F. Improper Start, Stop, Park
G. Traf. Control Viol'n. Lights
H. Traf. Control Viol'n. Signs
J. Fail to Yield R/W
K. Drove Left of Center
L. No or Improper Signal
M. Careless- Inattention
N. Avoid Vehicle, Object, Ped.
O. Bad Lane Change

# APPENDIX E. EB SAFETY PERFORMANCE FUNCTION – CALIBRATION COMPARISON

| | | | Average DEV Before | Average DEV After | % Change | Years of Data Before | Years of After Data |
|---|---|---|---|---|---|---|---|
| **1** | **MD** | Cearfoss/Hagerstown | 6,974 | 9,183 | 32% | 5 | 10.1 |
| **2** | **WA** | Duvall | 11,500 | 14,606 | 27% | 5.6 | 3.6 |
| **3** | **MD** | Federalsburg | 6,587 | 8,787 | 33% | 3.8 | 7 |
| **4** | **KS** | Florence | 4,848 | 4,751 | -2% | 8.75 | 1.75 |
| **5** | **KS** | Garnett | 5,086 | 5,828 | 15% | 5.3 | 1.67 |
| **6** | **MD** | Leeds | 8,270 | 10,793 | 31% | 5 | 10.4 |
| **7** | **MD** | Lisbon | 7,450 | 9,850 | 32% | 5 | 12.7 |
| **8** | **MD** | Lisbon | 8,504 | 10,125 | 19% | 4 | 7 |
| **9** | **MD** | Lothian | 13,808 | 17,383 | 26% | 5 | 10.2 |
| **10** | **MN** | New Prague | 6,700 | 7,225 | 8% | 6.6 | 2.3 |
| **11** | **MD** | North Harford | 8,058 | 9,341 | 16% | 5 | 5.3 |
| **12** | **KS** | Paola | 6,260 | 6,900 | 10% | 8.1 | 5.2 |
| **13** | **MD** | Rising Sun | 15,767 | 17,006 | 8% | 4 | 2 |
| **14** | **MD** | Rosemont | 13,467 | 13,814 | 3% | 3 | 5 |
| **15** | WA | Spokane | 10,200 | 10,821 | 6% | 6 | 3.6 |
| **16** | **OR** | Verboort | 9,253 | 10,016 | 8% | 2.5 | 3.2 |
| **17** | **OR** | Verboort | 10,980 | 11,886 | 8% | 2.5 | 3.2 |
| **18** | **WI** | Kaukauna | 9,000 | 8,950 | -1% | 6.5 | 2 |
| **19** | **WI** | Shebyogan Falls | 8,150 | 8,350 | 2% | 6.5 | 2 |
| | | | | | | 98.15 | 98.22 |

<0
0-5
6-10
11-20
21-30
31+

| | No Calibration Expected Injury Crashes/ Year After | Actual Injury Crashes / Year Before | Calibrated Model Expected Injury Crashes/ Year |
|---|---|---|---|
| **1** | 2.1 | 1.8 | 2.5 |
| **2** | 3.8 | 3.8 | 4.6 |
| **3** | 3.1 | 3.2 | 4.1 |
| **4** | 0.7 | 2.5 | 0.9 |
| **5** | 0.7 | 2.5 | 0.7 |
| **6** | 2.5 | 3.0 | 2.9 |
| **7** | 3.0 | 3.8 | 3.7 |
| **8** | 3.5 | 3.5 | 4.4 |
| **9** | 4.7 | 5.4 | 5.7 |
| **10** | 4.9 | 5.0 | 5.5 |
| **11** | 3.4 | 4.4 | 4.3 |
| **12** | 2.3 | 2.1 | 2.6 |
| **13** | 2.6 | 3.3 | 3.2 |
| **14** | 2.9 | 3.0 | 3.4 |
| **15** | 2.8 | 3.7 | 3.2 |
| **16** | 1.9 | 2.0 | 2.5 |
| **17** | 1.2 | 1.6 | 1.6 |
| **18** | 2.3 | 3.4 | 2.9 |
| **19** | 1.3 | 1.4 | 1.6 |
| | 49.6 | 59.2 | 60.6 |

| | No Calibration Expected Total Crashes/ Year After | Actual Total Crashes / Year Before | Calibrated Model Expected Total Crashes/ Year |
|---|---|---|---|
| **1** | 4.6 | 3.8 | 5.2 |
| **2** | 8.1 | 7.0 | 9.2 |
| **3** | 5.3 | 4.2 | 6.5 |
| **4** | 3.5 | 4.3 | 4.0 |
| **5** | 3.6 | 3.4 | 3.6 |
| **6** | 3.7 | 4.0 | 4.1 |
| **7** | 7.6 | 8.4 | 8.8 |
| **8** | 6.0 | 5.0 | 7.0 |
| **9** | 8.1 | 7.8 | 9.2 |
| **10** | 7.2 | 6.7 | 7.8 |
| **11** | 6.1 | 6.4 | 7.2 |
| **12** | 5.4 | 4.8 | 5.9 |
| **13** | 4.1 | 4.3 | 4.8 |
| **14** | 5.6 | 5.7 | 6.1 |
| **15** | 4.7 | 5.5 | 5.1 |
| **16** | 3.4 | 3.2 | 4.1 |
| **17** | 3.2 | 3.2 | 3.7 |
| **18** | 5.3 | 6.5 | 6.1 |
| **19** | 3.0 | 3.1 | 3.5 |
| | 98.4 | 97.2 | 112.1 |

# APPENDIX F.  STATISTICAL ANALYSIS OUTPUT - SAS

```
--------------------------------------------------------------------------

                         TOTAL CRASHES negbin

                         The GENMOD Procedure

                          Model Information

   Data Set                        WORK.WORK0
   Distribution             Negative Binomial
   Link Function                          Log
   Dependent Variable                CRASHTOT    CRASHTOT
   Offset Variable                  logYEARBA


                 Number of Observations Read           38
                 Number of Observations Used           38

                        Class Level Information

 Class          Levels    Values

 SITEID             19    1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
 PERIODID            2    0 1

                         Parameter Information

                  Parameter       Effect       PERIODID

                  Prm1            Intercept
                  Prm2            PERIODID     0
                  Prm3            PERIODID     1
                  Prm4            logDEV

                  Criteria For Assessing Goodness Of Fit

       Criterion                 DF           Value        Value/DF

       Deviance                  35         39.1392          1.1183
       Scaled Deviance           35         39.1392          1.1183
       Pearson Chi-Square        35         56.9804          1.6280
       Scaled Pearson X2         35         56.9804          1.6280
       Log Likelihood                     1575.3931


Algorithm converged.


--------------------------------------------------------------------------

                         TOTAL CRASHES negbin

                         The GENMOD Procedure

                 Analysis Of Initial Parameter Estimates

                                     Standard   Wald 95% Confidence      Chi-
Parameter         DF    Estimate       Error          Limits           Square
```

```
Intercept          1     -6.3942     2.6435   -11.5754     -1.2130       5.85
PERIODID     0     1      0.9926     0.1985     0.6036      1.3816      25.01
PERIODID     1     0      0.0000     0.0000     0.0000      0.0000        .
logDEV             1      0.7785     0.2842     0.2216      1.3355       7.51
Dispersion         1      0.2316     0.0698     0.0948      0.3684

                           Analysis Of Initial
                           Parameter Estimates

                       Parameter        Pr > ChiSq

                       Intercept            0.0156
                       PERIODID     0       <.0001
                       PERIODID     1         .
                       logDEV               0.0061
                       Dispersion

NOTE: The negative binomial dispersion parameter was estimated by maximum
      likelihood.


                          GEE Model Information

            Correlation Structure                  Exchangeable
            Subject Effect                    SITEID (19 levels)
            Number of Clusters                               19
            Correlation Matrix Dimension                      2
            Maximum Cluster Size                              2
            Minimum Cluster Size                              2


Algorithm converged.


                          Exchangeable Working
                               Correlation

                       Correlation    0.0182635268



--------------------------------------------------------------------------

                           TOTAL CRASHES negbin

                           The GENMOD Procedure

                   Analysis Of GEE Parameter Estimates
                    Empirical Standard Error Estimates

                          Standard   95% Confidence
     Parameter   Estimate    Error       Limits            Z Pr > |Z|

     Intercept     -6.3895   3.2383 -12.7365   -0.0426   -1.97   0.0485
     PERIODID  0    0.9921   0.1924   0.6150    1.3692    5.16   <.0001
     PERIODID  1    0.0000   0.0000   0.0000    0.0000     .       .
     logDEV         0.7780   0.3704   0.0521    1.5040    2.10   0.0357


                         Contrast Estimate Results

                  Standard                                 Chi-
Label  Estimate      Error    Alpha    Confidence Limits   Square   Pr > ChiSq

B-A      0.9921     0.1924     0.05     0.6150    1.3692    26.58       <.0001

--------------------------------------------------------------------------

                                 FREQ
```

```
                           The FREQ Procedure

                     Table of PERIODID by CRASHTOT

PERIODID(PERIODID)     CRASHTOT(CRASHTOT)

Frequency,
Percent  ,
Row Pct  ,
Col Pct  ,       1,       2,       3,       4,       5,       6,  Total
ƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆ
       0 ,      0 ,      0 ,      0 ,      0 ,      0 ,      0 ,     19
         ,   0.00 ,   0.00 ,   0.00 ,   0.00 ,   0.00 ,   0.00 ,  50.00
         ,   0.00 ,   0.00 ,   0.00 ,   0.00 ,   0.00 ,   0.00 ,
         ,   0.00 ,   0.00 ,   0.00 ,   0.00 ,   0.00 ,   0.00 ,
ƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆ
       1 ,      1 ,      1 ,      2 ,      4 ,      1 ,      1 ,     19
         ,   2.63 ,   2.63 ,   5.26 ,  10.53 ,   2.63 ,   2.63 ,  50.00
         ,   5.26 ,   5.26 ,  10.53 ,  21.05 ,   5.26 ,   5.26 ,
         , 100.00 , 100.00 , 100.00 , 100.00 , 100.00 , 100.00 ,
ƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆ
Total           1        1        2        4        1        1       38
             2.63     2.63     5.26    10.53     2.63     2.63   100.00
(Continued)
                     Table of PERIODID by CRASHTOT

PERIODID(PERIODID)     CRASHTOT(CRASHTOT)

Frequency,
Percent  ,
Row Pct  ,
Col Pct  ,       8,       9,      10,      11,      16,      17,  Total
ƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆ
       0 ,      2 ,      0 ,      0 ,      0 ,      1 ,      2 ,     19
         ,   5.26 ,   0.00 ,   0.00 ,   0.00 ,   2.63 ,   5.26 ,  50.00
         ,  10.53 ,   0.00 ,   0.00 ,   0.00 ,   5.26 ,  10.53 ,
         ,  66.67 ,   0.00 ,   0.00 ,   0.00 , 100.00 , 100.00 ,
ƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆ
       1 ,      1 ,      1 ,      2 ,      1 ,      0 ,      0 ,     19
         ,   2.63 ,   2.63 ,   5.26 ,   2.63 ,   0.00 ,   0.00 ,  50.00
         ,   5.26 ,   5.26 ,  10.53 ,   5.26 ,   0.00 ,   0.00 ,
         ,  33.33 , 100.00 , 100.00 , 100.00 ,   0.00 ,   0.00 ,
ƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆ
Total           3        1        2        1        1        2       38
             7.89     2.63     5.26     2.63     2.63     5.26   100.00
(Continued)

--------------------------------------------------------------------------

                                  FREQ

                           The FREQ Procedure

                     Table of PERIODID by CRASHTOT

PERIODID(PERIODID)     CRASHTOT(CRASHTOT)

Frequency,
Percent  ,
Row Pct  ,
Col Pct  ,      18,      19,      20,      22,      32,      33,  Total
ƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆ
       0 ,      1 ,      1 ,      3 ,      0 ,      1 ,      1 ,     19
         ,   2.63 ,   2.63 ,   7.89 ,   0.00 ,   2.63 ,   2.63 ,  50.00
         ,   5.26 ,   5.26 ,  15.79 ,   0.00 ,   5.26 ,   5.26 ,
         ,  50.00 , 100.00 , 100.00 ,   0.00 , 100.00 , 100.00 ,
ƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆ
       1 ,      1 ,      0 ,      0 ,      1 ,      0 ,      0 ,     19
```

```
          ,   2.63 ,   0.00 ,   0.00 ,   2.63 ,   0.00 ,   0.00 ,  50.00
          ,   5.26 ,   0.00 ,   0.00 ,   5.26 ,   0.00 ,   0.00 ,
          ,  50.00 ,   0.00 ,   0.00 , 100.00 ,   0.00 ,   0.00 ,
 fffffffffˆffffffffˆffffffffˆffffffffˆffffffffˆffffffffˆffffffffˆ
 Total           2        1        3        1        1        1       38
              5.26     2.63     7.89     2.63     2.63     2.63   100.00
 (Continued)
                      Table of PERIODID by CRASHTOT

 PERIODID(PERIODID)     CRASHTOT(CRASHTOT)

 Frequency,
 Percent  ,
 Row Pct  ,
 Col Pct  ,      38,      39,      40,      42,      44,      48,  Total
 fffffffffˆffffffffˆffffffffˆffffffffˆffffffffˆffffffffˆffffffffˆ
        0 ,       1 ,       3 ,       0 ,       2 ,       1 ,       0 ,     19
          ,   2.63 ,   7.89 ,   0.00 ,   5.26 ,   2.63 ,   0.00 ,  50.00
          ,   5.26 ,  15.79 ,   0.00 ,  10.53 ,   5.26 ,   0.00 ,
          , 100.00 , 100.00 ,   0.00 , 100.00 , 100.00 ,   0.00 ,
 fffffffffˆffffffffˆffffffffˆffffffffˆffffffffˆffffffffˆffffffffˆ
        1 ,       0 ,       0 ,       1 ,       0 ,       0 ,       1 ,     19
          ,   0.00 ,   0.00 ,   2.63 ,   0.00 ,   0.00 ,   2.63 ,  50.00
          ,   0.00 ,   0.00 ,   5.26 ,   0.00 ,   0.00 ,   5.26 ,
          ,   0.00 ,   0.00 , 100.00 ,   0.00 ,   0.00 , 100.00 ,
 fffffffffˆffffffffˆffffffffˆffffffffˆffffffffˆffffffffˆffffffffˆ
 Total           1        3        1        2        1        1       38
              2.63     7.89     2.63     5.26     2.63     2.63   100.00

--------------------------------------------------------------------------

                                   FREQ

                           The MEANS Procedure

                  Analysis Variable : CRASHTOT CRASHTOT

                  N
    PERIODID    Obs      N          Median           Range            Mean
fffffffffffffffffffffffffffffffffffffffffffffffffffffffffffffffffffffffff
           0     19     19           20.00           36.00           26.89

           1     19     19            6.00           47.00           11.16
fffffffffffffffffffffffffffffffffffffffffffffffffffffffffffffffffffffffff

                  Analysis Variable : CRASHTOT CRASHTOT

                                 N                       N
                   PERIODID    Obs         Std Dev    Miss
               fffffffffffffffffffffffffffffffffffffffffff
                          0     19           12.22       0

                          1     19           12.82       0
               fffffffffffffffffffffffffffffffffffffffffff

--------------------------------------------------------------------------

                                   FREQ

                         The UNIVARIATE Procedure
                     Variable:  CRASHTOT  (CRASHTOT)
                         PERIODID =            0

                                 Moments

     N                          19    Sum Weights                 19
     Mean               26.8947368    Sum Observations           511
     Std Deviation      12.2197233    Variance            149.321637
     Skewness           0.00166054    Kurtosis            -1.5666768
```

```
     Uncorrected SS          16431    Corrected SS        2687.78947
     Coeff Variation    45.4353704    Std Error Mean      2.80339679


                       Basic Statistical Measures

              Location                    Variability

          Mean     26.89474     Std Deviation           12.21972
          Median   20.00000     Variance               149.32164
          Mode     20.00000     Range                   36.00000
                                Interquartile Range     22.00000

  NOTE: The mode displayed is the smallest of 2 modes with a count of 3.


                       Tests for Location: Mu0=0

             Test           -Statistic-    -----p Value------

             Student's t    t  9.593625    Pr > |t|    <.0001
             Sign           M       9.5    Pr >= |M|   <.0001
             Signed Rank    S        95    Pr >= |S|   <.0001


                        Quantiles (Definition 5)

                         Quantile      Estimate

                         100% Max            44
                         99%                 44
                         95%                 44
                         90%                 42
                         75% Q3              39
                         50% Median          20
                         25% Q1              17
                         10%                  8
                         5%                   8
                         1%                   8
                         0% Min               8

--------------------------------------------------------------------------

                                  FREQ

                        The UNIVARIATE Procedure
                    Variable:  CRASHTOT  (CRASHTOT)
                        PERIODID =            0

                          Extreme Observations

                    ----Lowest----        ----Highest---

                    Value      Obs        Value      Obs

                        8       37           39       19
                        8       35           39       25
                       16        5           42       11
                       17       29           42       15
                       17       27           44       21

--------------------------------------------------------------------------

                                  FREQ

                        The UNIVARIATE Procedure
                    Variable:  CRASHTOT  (CRASHTOT)
                        PERIODID =            1
```

```
                                   Moments

N                          19    Sum Weights                 19
Mean               11.1578947    Sum Observations           212
Std Deviation      12.8247294    Variance            164.473684
Skewness           2.08442195    Kurtosis            3.85662907
Uncorrected SS           5326    Corrected SS        2960.52632
Coeff Variation    114.938613    Std Error Mean      2.94219471


                          Basic Statistical Measures

              Location                    Variability

          Mean     11.15789     Std Deviation            12.82473
          Median    6.00000     Variance                164.47368
          Mode      4.00000     Range                    47.00000
                                Interquartile Range       7.00000


                          Tests for Location: Mu0=0

              Test           -Statistic-    -----p Value------

              Student's t    t  3.792371    Pr > |t|    0.0013
              Sign           M       9.5    Pr >= |M|   <.0001
              Signed Rank    S        95    Pr >= |S|   <.0001


                           Quantiles (Definition 5)

                            Quantile      Estimate

                            100% Max            48
                            99%                 48
                            95%                 48
                            90%                 40
                            75% Q3              11
                            50% Median           6
                            25% Q1               4
                            10%                  2
                            5%                   1
                            1%                   1
                            0% Min               1


--------------------------------------------------------------------------

                                    FREQ

                          The UNIVARIATE Procedure
                      Variable:  CRASHTOT   (CRASHTOT)
                          PERIODID =           1

                            Extreme Observations

                      ----Lowest----        ----Highest---

                      Value      Obs        Value      Obs

                          1       34           11       26
                          2        8           18       16
                          3       32           22       14
                          3       30           40       20
                          4       24           48        4

--------------------------------------------------------------------------
```

```
                          INJURY CRASHES negbin

                           The GENMOD Procedure

                            Model Information

   Data Set                         WORK.WORK1
   Distribution              Negative Binomial
   Link Function                           Log
   Dependent Variable                 CRASHINJ    CRASHINJ
   Offset Variable                   logYEARBA


                 Number of Observations Read          38
                 Number of Observations Used          38


                         Class Level Information

 Class         Levels    Values

 SITEID            19    1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
 PERIODID           2    0 1


                          Parameter Information

                  Parameter       Effect       PERIODID

                  Prm1            Intercept
                  Prm2            PERIODID     0
                  Prm3            PERIODID     1
                  Prm4            logDEV


                  Criteria For Assessing Goodness Of Fit

       Criterion                 DF           Value        Value/DF

       Deviance                  35         42.9611          1.2275
       Scaled Deviance           35         42.9611          1.2275
       Pearson Chi-Square        35         43.8182          1.2519
       Scaled Pearson X2         35         43.8182          1.2519
       Log Likelihood                      547.0177


Algorithm converged.


--------------------------------------------------------------------------

                          INJURY CRASHES negbin

                           The GENMOD Procedure

                 Analysis Of Initial Parameter Estimates

                                  Standard   Wald 95% Confidence      Chi-
Parameter        DF    Estimate      Error         Limits           Square

Intercept         1     -6.6943     2.6829  -11.9527    -1.4360       6.23
PERIODID     0    1      2.0905     0.2199    1.6595     2.5216      90.36
PERIODID     1    0      0.0000     0.0000    0.0000     0.0000        .
logDEV            1      0.6371     0.2876    0.0735     1.2008       4.91
Dispersion        1      0.1271     0.0667   -0.0035     0.2578

                           Analysis Of Initial
                           Parameter Estimates
```

```
                       Parameter        Pr > ChiSq

                       Intercept            0.0126
                       PERIODID     0       <.0001
                       PERIODID     1         .
                       logDEV               0.0267
                       Dispersion

NOTE: The negative binomial dispersion parameter was estimated by maximum
      likelihood.


                          GEE Model Information

            Correlation Structure                    Exchangeable
            Subject Effect                     SITEID (19 levels)
            Number of Clusters                                 19
            Correlation Matrix Dimension                        2
            Maximum Cluster Size                                2
            Minimum Cluster Size                                2


Algorithm converged.


                          Exchangeable Working
                               Correlation

                       Correlation    0.0737304398



---------------------------------------------------------------------------

                          INJURY CRASHES negbin

                           The GENMOD Procedure

                   Analysis Of GEE Parameter Estimates
                    Empirical Standard Error Estimates

                          Standard   95% Confidence
     Parameter   Estimate    Error       Limits            Z Pr > |Z|

     Intercept     -6.4260    2.9360 -12.1805   -0.6715    -2.19   0.0286
     PERIODID  0    2.0806    0.2097    1.6696    2.4916     9.92   <.0001
     PERIODID  1    0.0000    0.0000    0.0000    0.0000      .       .
     logDEV         0.6082    0.3203   -0.0196    1.2360     1.90   0.0576


                        Contrast Estimate Results

                 Standard                                Chi-
Label  Estimate     Error    Alpha    Confidence Limits  Square   Pr > ChiSq

B-A      2.0806    0.2097     0.05     1.6696     2.4916   98.45      <.0001

---------------------------------------------------------------------------

                               INJURY FREQ

                            The FREQ Procedure

                      Table of PERIODID by CRASHINJ

      PERIODID(PERIODID)     CRASHINJ(CRASHINJ)

      Frequency,
```

```
Percent  ,
Row Pct  ,
Col Pct  ,       0,       1,       2,       3,       4,  Total
ƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆ
       0 ,      0 ,      0 ,      0 ,      0 ,      2 ,     19
         ,   0.00 ,   0.00 ,   0.00 ,   0.00 ,   5.26 ,  50.00
         ,   0.00 ,   0.00 ,   0.00 ,   0.00 ,  10.53 ,
         ,   0.00 ,   0.00 ,   0.00 ,   0.00 ,  66.67 ,
ƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆ
       1 ,      3 ,      8 ,      1 ,      4 ,      1 ,     19
         ,   7.89 ,  21.05 ,   2.63 ,  10.53 ,   2.63 ,  50.00
         ,  15.79 ,  42.11 ,   5.26 ,  21.05 ,   5.26 ,
         , 100.00 , 100.00 , 100.00 , 100.00 ,  33.33 ,
ƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆ
Total           3        8        1        4        3       38
             7.89    21.05     2.63    10.53     7.89   100.00
(Continued)
                Table of PERIODID by CRASHINJ

PERIODID(PERIODID)     CRASHINJ(CRASHINJ)

Frequency,
Percent  ,
Row Pct  ,
Col Pct  ,       5,       7,       9,      11,      12,  Total
ƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆ
       0 ,      1 ,      0 ,      3 ,      0 ,      1 ,     19
         ,   2.63 ,   0.00 ,   7.89 ,   0.00 ,   2.63 ,  50.00
         ,   5.26 ,   0.00 ,  15.79 ,   0.00 ,   5.26 ,
         , 100.00 ,   0.00 , 100.00 ,   0.00 , 100.00 ,
ƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆ
       1 ,      0 ,      1 ,      0 ,      1 ,      0 ,     19
         ,   0.00 ,   2.63 ,   0.00 ,   2.63 ,   0.00 ,  50.00
         ,   0.00 ,   5.26 ,   0.00 ,   5.26 ,   0.00 ,
         ,   0.00 , 100.00 ,   0.00 , 100.00 ,   0.00 ,
ƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆ
Total           1        1        3        1        1       38
             2.63     2.63     7.89     2.63     2.63   100.00
(Continued)

------------------------------------------------------------------------

                          INJURY FREQ

                       The FREQ Procedure

                Table of PERIODID by CRASHINJ

PERIODID(PERIODID)     CRASHINJ(CRASHINJ)

Frequency,
Percent  ,
Row Pct  ,
Col Pct  ,      13,      14,      15,      17,      19,  Total
ƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆ
       0 ,      1 ,      1 ,      1 ,      1 ,      1 ,     19
         ,   2.63 ,   2.63 ,   2.63 ,   2.63 ,   2.63 ,  50.00
         ,   5.26 ,   5.26 ,   5.26 ,   5.26 ,   5.26 ,
         , 100.00 , 100.00 , 100.00 , 100.00 , 100.00 ,
ƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆ
       1 ,      0 ,      0 ,      0 ,      0 ,      0 ,     19
         ,   0.00 ,   0.00 ,   0.00 ,   0.00 ,   0.00 ,  50.00
         ,   0.00 ,   0.00 ,   0.00 ,   0.00 ,   0.00 ,
         ,   0.00 ,   0.00 ,   0.00 ,   0.00 ,   0.00 ,
ƒƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆƒƒƒƒƒƒƒƒˆ
Total           1        1        1        1        1       38
             2.63     2.63     2.63     2.63     2.63   100.00
(Continued)
                Table of PERIODID by CRASHINJ
```

```
      PERIODID(PERIODID)     CRASHINJ(CRASHINJ)

      Frequency,
      Percent  ,
      Row Pct  ,
      Col Pct  ,      21,      22,      27,      33,  Total
      fffffffffˆffffffffˆffffffffˆffffffffˆffffffffˆ
             0 ,      1 ,      4 ,      1 ,      1 ,     19
               ,   2.63 ,  10.53 ,   2.63 ,   2.63 ,  50.00
               ,   5.26 ,  21.05 ,   5.26 ,   5.26 ,
               , 100.00 , 100.00 , 100.00 , 100.00 ,
      fffffffffˆffffffffˆffffffffˆffffffffˆffffffffˆ
             1 ,      0 ,      0 ,      0 ,      0 ,     19
               ,   0.00 ,   0.00 ,   0.00 ,   0.00 ,  50.00
               ,   0.00 ,   0.00 ,   0.00 ,   0.00 ,
               ,   0.00 ,   0.00 ,   0.00 ,   0.00 ,
      fffffffffˆffffffffˆffffffffˆffffffffˆffffffffˆ
      Total           1        4        1        1       38
                   2.63    10.53     2.63     2.63   100.00

---------------------------------------------------------------------------

                               INJURY FREQ

                           The MEANS Procedure

                  Analysis Variable : CRASHINJ CRASHINJ

                  N
    PERIODID    Obs     N          Median            Range             Mean
fffffffffffffffffffffffffffffffffffffffffffffffffffffffffffffffffffffffff
           0     19    19           15.00            29.00            15.74

           1     19    19            1.00            11.00             2.32
fffffffffffffffffffffffffffffffffffffffffffffffffffffffffffffffffffffffff

                  Analysis Variable : CRASHINJ CRASHINJ

                                 N                       N
                   PERIODID    Obs         Std Dev    Miss
               ffffffffffffffffffffffffffffffffffffffffffff
                          0     19            8.07       0

                          1     19            2.71       0
               ffffffffffffffffffffffffffffffffffffffffffff

---------------------------------------------------------------------------

                               INJURY FREQ

                         The UNIVARIATE Procedure
                     Variable:  CRASHINJ  (CRASHINJ)
                         PERIODID =           0

                                 Moments

     N                          19    Sum Weights                 19
     Mean               15.7368421    Sum Observations           299
     Std Deviation      8.07494138    Variance            65.2046784
     Skewness           0.26792344    Kurtosis             -0.476973
     Uncorrected SS           5879    Corrected SS        1173.68421
     Coeff Variation    51.3123366    Std Error Mean       1.8525186


                        Basic Statistical Measures

              Location                    Variability
```

```
          Mean     15.73684     Std Deviation            8.07494
          Median   15.00000     Variance                65.20468
          Mode     22.00000     Range                   29.00000
                                Interquartile Range     13.00000


                        Tests for Location: Mu0=0

             Test           -Statistic-    -----p Value------

             Student's t    t  8.494836    Pr > |t|    <.0001
             Sign           M       9.5    Pr >= |M|   <.0001
             Signed Rank    S        95    Pr >= |S|   <.0001


                         Quantiles (Definition 5)

                          Quantile      Estimate

                          100% Max            33
                          99%                 33
                          95%                 33
                          90%                 27
                          75% Q3              22
                          50% Median          15
                          25% Q1               9
                          10%                  4
                          5%                   4
                          1%                   4
                          0% Min               4



--------------------------------------------------------------------------

                               INJURY FREQ

                         The UNIVARIATE Procedure
                     Variable:  CRASHINJ  (CRASHINJ)
                         PERIODID =            0

                           Extreme Observations

                   ----Lowest----        ----Highest---

                   Value      Obs        Value      Obs

                       4       19           22        6
                       4        5           22       12
                       5       18           22       17
                       9       16           27       10
                       9       15           33       11

--------------------------------------------------------------------------

                               INJURY FREQ

                         The UNIVARIATE Procedure
                     Variable:  CRASHINJ  (CRASHINJ)
                         PERIODID =            1

                                 Moments

     N                          19    Sum Weights                 19
     Mean               2.31578947    Sum Observations            44
     Std Deviation      2.70909234    Variance            7.33918129
     Skewness           2.21180538    Kurtosis            5.48732046
     Uncorrected SS            234    Corrected SS        132.105263
     Coeff Variation    116.983533    Std Error Mean      0.62150841
```

```
                        Basic Statistical Measures

              Location                    Variability

          Mean     2.315789     Std Deviation            2.70909
          Median   1.000000     Variance                 7.33918
          Mode     1.000000     Range                   11.00000
                                Interquartile Range      2.00000

                        Tests for Location: Mu0=0

             Test           -Statistic-    -----p Value------

             Student's t    t  3.726079    Pr > |t|    0.0015
             Sign           M         8    Pr >= |M|   <.0001
             Signed Rank    S        68    Pr >= |S|   <.0001

                         Quantiles (Definition 5)

                          Quantile      Estimate

                          100% Max            11
                          99%                 11
                          95%                 11
                          90%                  7
                          75% Q3               3
                          50% Median           1
                          25% Q1               1
                          10%                  0
                          5%                   0
                          1%                   0
                          0% Min               0


--------------------------------------------------------------------------

                               INJURY FREQ

                         The UNIVARIATE Procedure
                     Variable:  CRASHINJ  (CRASHINJ)
                         PERIODID =             1

                           Extreme Observations

                   ----Lowest----        ----Highest---

                   Value      Obs        Value      Obs

                       0       36            3       33
                       0       32            3       34
                       0       23            4       27
                       1       38            7       21
                       1       37           11       29

--------------------------------------------------------------------------

                            CRASH TYPES negbin

                           The GENMOD Procedure

                            Model Information

   Data Set                        WORK.WORK2
   Distribution              Negative Binomial
```

```
   Link Function                          Log
   Dependent Variable              CRASHTYPES    CRASHTYPES
   Offset Variable                  logYEARBA


                 Number of Observations Read         190
                 Number of Observations Used         190


                         Class Level Information

 Class         Levels    Values

 SITEID            19    1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
 PERIODID           2    0 1
 TYPESID            5    1 2 3 4 5


                          Parameter Information

         Parameter       Effect              PERIODID    TYPESID

         Prm1            Intercept
         Prm2            CRASHTOT
         Prm3            TYPESID                         1
         Prm4            TYPESID                         2
         Prm5            TYPESID                         3
         Prm6            TYPESID                         4
         Prm7            TYPESID                         5
         Prm8            PERIODID            0
         Prm9            PERIODID            1
         Prm10           logDEV
         Prm11           SPDMAX
         Prm12           LEGS
         Prm13           PERIODID*TYPESID    0           1
         Prm14           PERIODID*TYPESID    0           2
         Prm15           PERIODID*TYPESID    0           3
         Prm16           PERIODID*TYPESID    0           4
         Prm17           PERIODID*TYPESID    0           5
         Prm18           PERIODID*TYPESID    1           1
         Prm19           PERIODID*TYPESID    1           2
         Prm20           PERIODID*TYPESID    1           3
         Prm21           PERIODID*TYPESID    1           4
         Prm22           PERIODID*TYPESID    1           5

--------------------------------------------------------------------------

                            CRASH TYPES negbin

                           The GENMOD Procedure

                  Criteria For Assessing Goodness Of Fit

       Criterion                 DF           Value        Value/DF

       Deviance                 176        202.4132          1.1501
       Scaled Deviance          176        202.4132          1.1501
       Pearson Chi-Square       176        250.6396          1.4241
       Scaled Pearson X2        176        250.6396          1.4241
       Log Likelihood                      884.4287


Algorithm converged.


                 Analysis Of Initial Parameter Estimates

                                           Standard   Wald 95% Confidence
Parameter                  DF    Estimate     Error          Limits
```

```
Intercept                   1    -8.0600     4.2290   -16.3487     0.2286
CRASHTOT                    1     0.0338     0.0072     0.0198     0.0478
TYPESID            1        1     1.0349     0.4405     0.1716     1.8982
TYPESID            2        1     0.8523     0.4504    -0.0304     1.7351
TYPESID            3        1     0.3005     0.4697    -0.6200     1.2210
TYPESID            4        1     1.5168     0.4322     0.6696     2.3640
TYPESID            5        0     0.0000     0.0000     0.0000     0.0000
PERIODID           0        1     0.2640     0.4705    -0.6582     1.1861
PERIODID           1        0     0.0000     0.0000     0.0000     0.0000
logDEV                      1     0.6872     0.3830    -0.0635     1.4379
SPDMAX                      1     0.0378     0.0169     0.0046     0.0709
LEGS                        1    -0.6231     0.2117    -1.0379    -0.2082

                 Analysis Of Initial Parameter Estimates

                                          Chi-
             Parameter                  Square    Pr > ChiSq

             Intercept                    3.63        0.0567
             CRASHTOT                    22.26        <.0001
             TYPESID            1         5.52        0.0188
             TYPESID            2         3.58        0.0584
             TYPESID            3         0.41        0.5223
             TYPESID            4        12.31        0.0004
             TYPESID            5          .           .
             PERIODID           0         0.31        0.5747
             PERIODID           1          .           .
             logDEV                       3.22        0.0728
             SPDMAX                       4.98        0.0256
             LEGS                         8.66        0.0032

--------------------------------------------------------------------------

                            CRASH TYPES negbin

                           The GENMOD Procedure

                 Analysis Of Initial Parameter Estimates

                                          Standard   Wald 95% Confidence
Parameter                  DF   Estimate     Error         Limits

PERIODID*TYPESID   0   1    1     1.4933     0.5599     0.3958     2.5907
PERIODID*TYPESID   0   2    1    -0.0992     0.5815    -1.2390     1.0406
PERIODID*TYPESID   0   3    1    -1.2875     0.6370    -2.5360    -0.0391
PERIODID*TYPESID   0   4    1    -1.8031     0.5920    -2.9634    -0.6427
PERIODID*TYPESID   0   5    0     0.0000     0.0000     0.0000     0.0000
PERIODID*TYPESID   1   1    0     0.0000     0.0000     0.0000     0.0000
PERIODID*TYPESID   1   2    0     0.0000     0.0000     0.0000     0.0000
PERIODID*TYPESID   1   3    0     0.0000     0.0000     0.0000     0.0000
PERIODID*TYPESID   1   4    0     0.0000     0.0000     0.0000     0.0000
PERIODID*TYPESID   1   5    0     0.0000     0.0000     0.0000     0.0000
Dispersion                  1     0.6915     0.1418     0.4135     0.9695

                 Analysis Of Initial Parameter Estimates

                                          Chi-
             Parameter                  Square    Pr > ChiSq

             PERIODID*TYPESID   0   1     7.11        0.0077
             PERIODID*TYPESID   0   2     0.03        0.8645
             PERIODID*TYPESID   0   3     4.09        0.0432
             PERIODID*TYPESID   0   4     9.28        0.0023
             PERIODID*TYPESID   0   5      .           .
             PERIODID*TYPESID   1   1      .           .
             PERIODID*TYPESID   1   2      .           .
             PERIODID*TYPESID   1   3      .           .
             PERIODID*TYPESID   1   4      .           .
```

```
             PERIODID*TYPESID   1   5       .           .
             Dispersion

NOTE: The negative binomial dispersion parameter was estimated by maximum
      likelihood.


                          GEE Model Information

            Correlation Structure                  Exchangeable
            Subject Effect                   SITEID (19 levels)
            Number of Clusters                               19
            Correlation Matrix Dimension                     10
            Maximum Cluster Size                             10
            Minimum Cluster Size                             10


Algorithm converged.

---------------------------------------------------------------------------

                            CRASH TYPES negbin

                           The GENMOD Procedure

                          Exchangeable Working
                               Correlation

                       Correlation    -0.001606133


                   Analysis Of GEE Parameter Estimates
                   Empirical Standard Error Estimates

                               Standard   95% Confidence
Parameter             Estimate    Error       Limits           Z Pr > |Z|

Intercept              -8.0564   3.7636 -15.4329  -0.6799   -2.14   0.0323
CRASHTOT                0.0338   0.0112   0.0119   0.0558    3.02   0.0025
TYPESID          1      1.0347   0.4394   0.1735   1.8959    2.35   0.0185
TYPESID          2      0.8524   0.4140   0.0411   1.6638    2.06   0.0395
TYPESID          3      0.2999   0.7916  -1.2516   1.8514    0.38   0.7048
TYPESID          4      1.5171   0.4225   0.6890   2.3452    3.59   0.0003
TYPESID          5      0.0000   0.0000   0.0000   0.0000     .       .
PERIODID         0      0.2626   0.4072  -0.5355   1.0608    0.64   0.5190
PERIODID         1      0.0000   0.0000   0.0000   0.0000     .       .
logDEV                  0.6861   0.3458   0.0084   1.3637    1.98   0.0472
SPDMAX                  0.0379   0.0115   0.0153   0.0605    3.28   0.0010
LEGS                   -0.6228   0.1241  -0.8660  -0.3796   -5.02   <.0001
PERIODID*TYPESID 0 1    1.4939   0.5746   0.3677   2.6201    2.60   0.0093
PERIODID*TYPESID 0 2   -0.0989   0.4727  -1.0254   0.8276   -0.21   0.8342
PERIODID*TYPESID 0 3   -1.2871   0.6313  -2.5244  -0.0499   -2.04   0.0414
PERIODID*TYPESID 0 4   -1.8031   0.5008  -2.7846  -0.8216   -3.60   0.0003
PERIODID*TYPESID 0 5    0.0000   0.0000   0.0000   0.0000     .       .
PERIODID*TYPESID 1 1    0.0000   0.0000   0.0000   0.0000     .       .
PERIODID*TYPESID 1 2    0.0000   0.0000   0.0000   0.0000     .       .
PERIODID*TYPESID 1 3    0.0000   0.0000   0.0000   0.0000     .       .
PERIODID*TYPESID 1 4    0.0000   0.0000   0.0000   0.0000     .       .
PERIODID*TYPESID 1 5    0.0000   0.0000   0.0000   0.0000     .       .


                        Contrast Estimate Results

                                                   Standard
      Label                            Estimate       Error      Alpha

      B-A                               -0.0764      0.2150       0.05

                        Contrast Estimate Results
```

```
                                                        Chi-
Label                            Confidence Limits    Square   Pr > ChiSq

B-A                              -0.4978     0.3450     0.13       0.7223

--------------------------------------------------------------------------

                            CRASH TYPES negbin

                           The GENMOD Procedure

                        Contrast Estimate Results

                                                  Standard
      Label                           Estimate       Error     Alpha

      TYPE-ANG in Before v.s. After     1.7565      0.3386      0.05
      TYPE-REN in Before v.s. After     0.1637      0.2162      0.05
      TYPE-SWI in Before v.s. After    -1.0245      0.5403      0.05
      TYPE-FIX in Before v.s. After    -1.5405      0.4406      0.05
      TYPE-OTH in Before v.s. After     0.2626      0.4072      0.05

                        Contrast Estimate Results

                                                        Chi-
Label                            Confidence Limits    Square   Pr > ChiSq

TYPE-ANG in Before v.s. After     1.0928     2.4202    26.91       <.0001
TYPE-REN in Before v.s. After    -0.2600     0.5874     0.57       0.4489
TYPE-SWI in Before v.s. After    -2.0835     0.0345     3.60       0.0579
TYPE-FIX in Before v.s. After    -2.4041    -0.6769    12.22       0.0005
TYPE-OTH in Before v.s. After    -0.5355     1.0608     0.42       0.5190

--------------------------------------------------------------------------

                          CRASH SEVERITY2 negbin

                           The GENMOD Procedure

                            Model Information

   Data Set                     WORK.WORK3
   Distribution          Negative Binomial
   Link Function                       Log
   Dependent Variable             CRASHSEV    CRASHSEV
   Offset Variable               logYEARBA


                 Number of Observations Read          76
                 Number of Observations Used          76


                         Class Level Information

 Class         Levels    Values

 SITEID            19    1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19
 PERIODID           2    0 1
 SEVID              2    1 2


                          Parameter Information

           Parameter       Effect            PERIODID    SEVID

           Prm1            Intercept
           Prm2            CRASHTOT
           Prm3            SEVID                         1
```

```
                Prm4            SEVID                          2
                Prm5            PERIODID          0
                Prm6            PERIODID          1
                Prm7            logDEV
                Prm8            LEGS
                Prm9            PERIODID*SEVID    0            1
                Prm10           PERIODID*SEVID    0            2
                Prm11           PERIODID*SEVID    1            1
                Prm12           PERIODID*SEVID    1            2


                       Criteria For Assessing Goodness Of Fit

            Criterion                 DF           Value        Value/DF

            Deviance                  69         81.8515          1.1863
            Scaled Deviance           69         81.8515          1.1863
            Pearson Chi-Square        69         85.7952          1.2434
            Scaled Pearson X2         69         85.7952          1.2434
            Log Likelihood                     1144.2811

-------------------------------------------------------------------------

                               CRASH SEVERITY2 negbin

                                The GENMOD Procedure

Algorithm converged.


                      Analysis Of Initial Parameter Estimates

                                          Standard       Wald 95%          Chi-
Parameter            DF   Estimate       Error    Confidence Limits    Square

Intercept              1    -2.3161     1.9464   -6.1311     1.4988      1.42
CRASHTOT               1     0.0342     0.0043    0.0257     0.0427     61.88
SEVID          1       1    -1.3551     0.2045   -1.7559    -0.9543     43.92
SEVID          2       0     0.0000     0.0000    0.0000     0.0000       .
PERIODID       0       1    -0.1059     0.1632   -0.4259     0.2140      0.42
PERIODID       1       0     0.0000     0.0000    0.0000     0.0000       .
logDEV                 1     0.3432     0.1841   -0.0177     0.7041      3.47
LEGS                   1    -0.2327     0.1375   -0.5021     0.0367      2.87
PERIODID*SEVID 0  1    1     1.7095     0.2411    1.2369     2.1820     50.27
PERIODID*SEVID 0  2    0     0.0000     0.0000    0.0000     0.0000       .
PERIODID*SEVID 1  1    0     0.0000     0.0000    0.0000     0.0000       .
PERIODID*SEVID 1  2    0     0.0000     0.0000    0.0000     0.0000       .
Dispersion             1     0.0671     0.0288    0.0107     0.1235

                              Analysis Of Initial
                              Parameter Estimates

                     Parameter             Pr > ChiSq

                     Intercept                 0.2341
                     CRASHTOT                  <.0001
                     SEVID          1          <.0001
                     SEVID          2           .
                     PERIODID       0          0.5165
                     PERIODID       1           .
                     logDEV                    0.0623
                     LEGS                      0.0905
                     PERIODID*SEVID 0  1       <.0001
                     PERIODID*SEVID 0  2        .
                     PERIODID*SEVID 1  1        .
                     PERIODID*SEVID 1  2        .
                     Dispersion

NOTE: The negative binomial dispersion parameter was estimated by maximum
```

```
      likelihood.

                                GEE Model Information

            Correlation Structure                 Exchangeable
            Subject Effect                  SITEID (19 levels)
            Number of Clusters                              19
            Correlation Matrix Dimension                     4

--------------------------------------------------------------------------

                                CRASH SEVERITY2 negbin

                                 The GENMOD Procedure

                                GEE Model Information

            Maximum Cluster Size                             4
            Minimum Cluster Size                             4


Algorithm converged.


                                 Exchangeable Working
                                     Correlation

                              Correlation    -0.13755872


                         Analysis Of GEE Parameter Estimates
                         Empirical Standard Error Estimates

                                   Standard   95% Confidence
 Parameter          Estimate     Error       Limits            Z Pr > |Z|

 Intercept            -2.4024   1.3894  -5.1257   0.3208   -1.73   0.0838
 CRASHTOT              0.0337   0.0059   0.0222   0.0452    5.73   <.0001
 SEVID           1    -1.3606   0.2024  -1.7572  -0.9640   -6.72   <.0001
 SEVID           2     0.0000   0.0000   0.0000   0.0000     .       .
 PERIODID        0    -0.0886   0.2151  -0.5102   0.3330   -0.41   0.6804
 PERIODID        1     0.0000   0.0000   0.0000   0.0000     .       .
 logDEV                0.3564   0.1361   0.0896   0.6231    2.62   0.0088
 LEGS                 -0.2367   0.0833  -0.3999  -0.0735   -2.84   0.0045
 PERIODID*SEVID 0 1   1.7133   0.2010   1.3194   2.1073    8.52   <.0001
 PERIODID*SEVID 0 2   0.0000   0.0000   0.0000   0.0000     .       .
 PERIODID*SEVID 1 1   0.0000   0.0000   0.0000   0.0000     .       .
 PERIODID*SEVID 1 2   0.0000   0.0000   0.0000   0.0000     .       .


                              Contrast Estimate Results

                                                          Standard
      Label                              Estimate           Error     Alpha

      SEVE-INJ in Before v.s. After        1.6247          0.1830      0.05
      SEVE-PDO in Before v.s. After       -0.0886          0.2151      0.05

                              Contrast Estimate Results

                                                                Chi-
Label                            Confidence Limits       Square    Pr > ChiSq

SEVE-INJ in Before v.s. After     1.2661      1.9833     78.86        <.0001
SEVE-PDO in Before v.s. After    -0.5102      0.3330      0.17        0.6804

--------------------------------------------------------------------------
```

```
                              INJURY BY TYPE negbin

                               The GENMOD Procedure

                                Model Information

            Data Set                      WORK.WORK4
            Distribution           Negative Binomial
            Link Function                        Log
            Dependent Variable          INJCRASHTYPES    INJCRASHTYPES
            Offset Variable                 logYEARBA


                   Number of Observations Read         140
                   Number of Observations Used         140


                             Class Level Information

              Class         Levels    Values

              SITEID            14    1 2 4 5 6 8 11 13 14 15 16 17 18 19
              PERIODID           2    0 1
              TYPESID            5    1 2 3 4 5


                              Parameter Information

                Parameter       Effect              PERIODID    TYPESID

                Prm1            Intercept
                Prm2            CRASHINJ
                Prm3            TYPESID                         1
                Prm4            TYPESID                         2
                Prm5            TYPESID                         3
                Prm6            TYPESID                         4
                Prm7            TYPESID                         5
                Prm8            PERIODID            0
                Prm9            PERIODID            1
                Prm10           logDEV
                Prm11           LEGS
                Prm12           PERIODID*TYPESID    0           1
                Prm13           PERIODID*TYPESID    0           2
                Prm14           PERIODID*TYPESID    0           3
                Prm15           PERIODID*TYPESID    0           4
                Prm16           PERIODID*TYPESID    0           5
                Prm17           PERIODID*TYPESID    1           1
                Prm18           PERIODID*TYPESID    1           2
                Prm19           PERIODID*TYPESID    1           3
                Prm20           PERIODID*TYPESID    1           4
                Prm21           PERIODID*TYPESID    1           5
--------------------------------------------------------------------------
                              INJURY BY TYPE negbin

                               The GENMOD Procedure

                      Criteria For Assessing Goodness Of Fit

              Criterion                 DF           Value        Value/DF

              Deviance                 127        141.3208          1.1128
              Scaled Deviance          127        141.3208          1.1128
              Pearson Chi-Square       127        197.8890          1.5582
              Scaled Pearson X2        127        197.8890          1.5582
              Log Likelihood                      164.8259
```

```
Algorithm converged.

                 Analysis Of Initial Parameter Estimates

                                           Standard   Wald 95% Confidence
Parameter                  DF    Estimate       Error          Limits

Intercept                   1   -12.1275     3.6608   -19.3026    -4.9524
CRASHINJ                    1     0.0441     0.0148     0.0151     0.0731
TYPESID            1        1     1.1012     0.8467    -0.5582     2.7607
TYPESID            2        1     1.1240     0.8465    -0.5350     2.7831
TYPESID            3        1     0.9326     0.8657    -0.7642     2.6294
TYPESID            4        1     1.4200     0.8214    -0.1898     3.0299
TYPESID            5        0     0.0000     0.0000     0.0000     0.0000
PERIODID           0        1     1.1091     0.8264    -0.5107     2.7289
PERIODID           1        0     0.0000     0.0000     0.0000     0.0000
logDEV                      1     0.9792     0.3360     0.3206     1.6378
LEGS                        1    -0.0966     0.2615    -0.6092     0.4160
PERIODID*TYPESID   0   1    1     1.3918     0.9192    -0.4098     3.1935

                 Analysis Of Initial Parameter Estimates

                                           Chi-
             Parameter                   Square    Pr > ChiSq

             Intercept                    10.97        0.0009
             CRASHINJ                      8.90        0.0028
             TYPESID            1          1.69        0.1934
             TYPESID            2          1.76        0.1842
             TYPESID            3          1.16        0.2814
             TYPESID            4          2.99        0.0838
             TYPESID            5            .           .
             PERIODID           0          1.80        0.1796
             PERIODID           1            .           .
             logDEV                        8.49        0.0036
             LEGS                          0.14        0.7118
             PERIODID*TYPESID   0   1      2.29        0.1300

--------------------------------------------------------------------------

                          INJURY BY TYPE negbin

                           The GENMOD Procedure

                 Analysis Of Initial Parameter Estimates

                                           Standard   Wald 95% Confidence
Parameter                  DF    Estimate       Error          Limits

PERIODID*TYPESID   0   2    1    -0.4492     0.9389    -2.2894     1.3910
PERIODID*TYPESID   0   3    1    -1.4087     0.9998    -3.3683     0.5510
PERIODID*TYPESID   0   4    1    -2.1345     0.9819    -4.0589    -0.2101
PERIODID*TYPESID   0   5    0     0.0000     0.0000     0.0000     0.0000
PERIODID*TYPESID   1   1    0     0.0000     0.0000     0.0000     0.0000
PERIODID*TYPESID   1   2    0     0.0000     0.0000     0.0000     0.0000
PERIODID*TYPESID   1   3    0     0.0000     0.0000     0.0000     0.0000
PERIODID*TYPESID   1   4    0     0.0000     0.0000     0.0000     0.0000
PERIODID*TYPESID   1   5    0     0.0000     0.0000     0.0000     0.0000
Dispersion                  1     0.2146     0.1825    -0.0313     0.5722

                 Analysis Of Initial Parameter Estimates

                                           Chi-
             Parameter                   Square    Pr > ChiSq

             PERIODID*TYPESID   0   2      0.23        0.6323
             PERIODID*TYPESID   0   3      1.98        0.1589
             PERIODID*TYPESID   0   4      4.73        0.0297
```

```
                PERIODID*TYPESID   0   5       .           .
                PERIODID*TYPESID   1   1       .           .
                PERIODID*TYPESID   1   2       .           .
                PERIODID*TYPESID   1   3       .           .
                PERIODID*TYPESID   1   4       .           .
                PERIODID*TYPESID   1   5       .           .
                Dispersion

   NOTE: The negative binomial dispersion parameter was estimated by maximum
         likelihood.


                              GEE Model Information

               Correlation Structure                 Exchangeable
               Subject Effect                    SITEID (14 levels)
               Number of Clusters                              14
               Correlation Matrix Dimension                    10
               Maximum Cluster Size                            10
               Minimum Cluster Size                            10


   Algorithm converged.

   ---------------------------------------------------------------------------

                              INJURY BY TYPE negbin

                               The GENMOD Procedure

                              Exchangeable Working
                                   Correlation

                           Correlation    -0.019710884


                       Analysis Of GEE Parameter Estimates
                       Empirical Standard Error Estimates

                                    Standard   95% Confidence
   Parameter             Estimate      Error       Limits            Z Pr > |Z|

   Intercept             -11.6795     2.6138 -16.8024  -6.5566   -4.47   <.0001
   CRASHINJ                0.0471     0.0092   0.0290   0.0651    5.11   <.0001
   TYPESID          1      1.0964     0.4771   0.1614   2.0314    2.30   0.0215
   TYPESID          2      1.1187     0.6123  -0.0814   2.3188    1.83   0.0677
   TYPESID          3      0.9290     0.8680  -0.7722   2.6302    1.07   0.2845
   TYPESID          4      1.4154     0.7942  -0.1413   2.9720    1.78   0.0747
   TYPESID          5      0.0000     0.0000   0.0000   0.0000     .       .
   PERIODID         0      1.0658     0.7819  -0.4667   2.5984    1.36   0.1729
   PERIODID         1      0.0000     0.0000   0.0000   0.0000     .       .
   logDEV                  0.9599     0.2412   0.4872   1.4326    3.98   <.0001
   LEGS                   -0.1632     0.0975  -0.3543   0.0280   -1.67   0.0944
   PERIODID*TYPESID 0 1    1.3935     0.8762  -0.3238   3.1109    1.59   0.1117
   PERIODID*TYPESID 0 2   -0.4418     0.7430  -1.8980   1.0145   -0.59   0.5521
   PERIODID*TYPESID 0 3   -1.4044     1.0143  -3.3923   0.5835   -1.38   0.1662
   PERIODID*TYPESID 0 4   -2.1267     1.0632  -4.2105  -0.0429   -2.00   0.0455
   PERIODID*TYPESID 0 5    0.0000     0.0000   0.0000   0.0000     .       .
   PERIODID*TYPESID 1 1    0.0000     0.0000   0.0000   0.0000     .       .
   PERIODID*TYPESID 1 2    0.0000     0.0000   0.0000   0.0000     .       .
   PERIODID*TYPESID 1 3    0.0000     0.0000   0.0000   0.0000     .       .
   PERIODID*TYPESID 1 4    0.0000     0.0000   0.0000   0.0000     .       .
   PERIODID*TYPESID 1 5    0.0000     0.0000   0.0000   0.0000     .       .


                            Contrast Estimate Results

                                                            Standard
         Label                               Estimate          Error      Alpha
```

```
      B-A                               0.5500      0.2830      0.05
      TYPE-ANG in Before v.s. After     2.4594      0.3336      0.05

                        Contrast Estimate Results

                                                        Chi-
Label                            Confidence Limits    Square   Pr > ChiSq

B-A                              -0.0046     1.1045     3.78       0.0519
TYPE-ANG in Before v.s. After     1.8056     3.1131    54.36       <.0001

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                          INJURY BY TYPE negbin

                           The GENMOD Procedure

                        Contrast Estimate Results

                                                  Standard
      Label                           Estimate       Error     Alpha

      TYPE-REN in Before v.s. After     0.6241      0.3724      0.05
      TYPE-SWI in Before v.s. After    -0.3386      0.5270      0.05
      TYPE-FIX in Before v.s. After    -1.0609      0.7335      0.05
      TYPE-OTH in Before v.s. After     1.0658      0.7819      0.05

                        Contrast Estimate Results

                                                        Chi-
Label                            Confidence Limits    Square   Pr > ChiSq

TYPE-REN in Before v.s. After    -0.1059     1.3540     2.81       0.0938
TYPE-SWI in Before v.s. After    -1.3715     0.6943     0.41       0.5206
TYPE-FIX in Before v.s. After    -2.4985     0.3768     2.09       0.1481
TYPE-OTH in Before v.s. After    -0.4667     2.5984     1.86       0.1729
```

```
--------------------------------------------------------------------------

                     TOTAL CRASHES negbin AFTER ONLY

                           The GENMOD Procedure

                            Model Information

   Data Set                      WORK.WORK0
   Distribution           Negative Binomial
   Link Function                        Log
   Dependent Variable              CRASHTOT    CRASHTOT
   Offset Variable                logYEARBA


                 Number of Observations Read          18
                 Number of Observations Used          18


                         Class Level Information

   Class       Levels    Values

   SITEID          18    1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18


                 Criteria For Assessing Goodness Of Fit

       Criterion                 DF           Value        Value/DF

       Deviance                  16         18.2609          1.1413
       Scaled Deviance           16         18.2609          1.1413
       Pearson Chi-Square        16         15.3032          0.9564
       Scaled Pearson X2         16         15.3032          0.9564
       Log Likelihood                      245.3728

Algorithm converged.


                     Analysis Of Parameter Estimates

                                 Standard   Wald 95% Confidence      Chi-
  Parameter     DF    Estimate      Error          Limits           Square

  Intercept      1     -6.1810     3.8508   -13.7285      1.3664      2.58
  logDEV         1      0.7274     0.4160    -0.0879      1.5428      3.06

                          Analysis Of Parameter
                                Estimates

                        Parameter     Pr > ChiSq

                        Intercept         0.1085
                        logDEV            0.0804

--------------------------------------------------------------------------

                     TOTAL CRASHES negbin AFTER ONLY

                           The GENMOD Procedure

                     Analysis Of Parameter Estimates

                                 Standard   Wald 95% Confidence      Chi-
  Parameter     DF    Estimate      Error          Limits           Square

  Dispersion     1      0.1525     0.0983    -0.0250      0.3451
```

```
                          Analysis Of Parameter
                                Estimates

                         Parameter    Pr > ChiSq

                         Dispersion

NOTE: The negative binomial dispersion parameter was estimated by maximum
      likelihood.

--------------------------------------------------------------------------

                     TOTAL CRASHES negbin AFTER ONLY

                           The GENMOD Procedure

                            Model Information

   Data Set                        WORK.WORK0
   Distribution             Negative Binomial
   Link Function                          Log
   Dependent Variable                CRASHTOT    CRASHTOT
   Offset Variable                  logYEARBA


                 Number of Observations Read          18
                 Number of Observations Used          18


                         Class Level Information

   Class       Levels    Values

   SITEID          18    1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18


                  Criteria For Assessing Goodness Of Fit

       Criterion                 DF           Value        Value/DF

       Deviance                  16         18.2609          1.1413
       Scaled Deviance           16         18.2609          1.1413
       Pearson Chi-Square        16         15.3032          0.9564
       Scaled Pearson X2         16         15.3032          0.9564
       Log Likelihood                      245.3728


Algorithm converged.


                     Analysis Of Parameter Estimates

                                Standard   Wald 95% Confidence       Chi-
  Parameter     DF    Estimate     Error         Limits            Square

  Intercept      1     -6.1810    3.8508   -13.7285      1.3664      2.58
  logDEV         1      0.7274    0.4160    -0.0879      1.5428      3.06

                          Analysis Of Parameter
                                Estimates

                         Parameter    Pr > ChiSq

                         Intercept        0.1085
                         logDEV           0.0804

--------------------------------------------------------------------------
```

```
                       TOTAL CRASHES negbin AFTER ONLY

                             The GENMOD Procedure

                       Analysis Of Parameter Estimates

                                  Standard   Wald 95% Confidence      Chi-
 Parameter     DF    Estimate       Error          Limits           Square

 Dispersion     1      0.1525      0.0983     -0.0250     0.3451

                            Analysis Of Parameter
                                  Estimates

                           Parameter    Pr > ChiSq

                           Dispersion

NOTE: The negative binomial dispersion parameter was estimated by maximum
      likelihood.


                          Observation Statistics

 Observation     CRASHTOT    logYEARBA       logDEV   SITEID        Pred
                                 Xbeta          Std     HessWgt       Lower
                                 Upper       Resraw      Reschi      Resdev
                              StResdev     StReschi      Reslik

           1            9    2.3125354    9.1251092   1         15.949406
                             2.7694216     0.140913   3.2124711   12.100384
                             21.022769    -6.949406   -0.939306   -1.091186
                              -1.14413    -0.984881   -1.130655
           2           10    1.9459101    9.0810286   2         10.705211
                             2.3707306    0.1487304   3.9007387   7.9982627
                             14.328304    -0.705211   -0.132848   -0.135289
                             -0.141767    -0.139209    -0.14154
           3            2    0.5596158    8.4661104   3         1.7110786
                             0.5371239    0.3518995    1.404442   0.8584848
                             3.4104157    0.2889214      0.1967   0.1904502
                             0.2119049    0.2188588   0.2132594
           4            4    0.5128236    8.6704292   4         1.8945099
                             0.6389602    0.2748077    1.836032   1.1055545
                             3.2464864    2.1054901   1.3474119   1.1322823
                             1.2097489    1.4395969   1.2405578
           5            4    0.6931472    9.0994088   5         3.0998013
                              1.131338    0.1452407   2.3011069   2.3318721
                              4.120624    0.9001987   0.4213296   0.3972924
                             0.4062926    0.4308744   0.4074007
           6           22    2.3418058    9.2866531   6         18.471046
                             2.9162044    0.1315558   5.5222909   14.272859
                             23.904079    3.5289537   0.4203129     0.39909
                             0.4168445    0.4390116   0.4187375

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                       TOTAL CRASHES negbin AFTER ONLY

                             The GENMOD Procedure

                          Observation Statistics

 Observation     CRASHTOT    logYEARBA       logDEV   SITEID        Pred
                                 Xbeta          Std     HessWgt       Lower
                                 Upper       Resraw      Reschi      Resdev
                              StResdev     StReschi      Reslik

           7           18     2.541602    9.1952267   7         21.104663
                              3.049494    0.1328175   4.4419551   16.267618
```

```
                           27.379965   -3.104663   -0.329059   -0.344476
                           -0.360276   -0.344152   -0.358921
           8           6   1.9459101   9.2227629   8        11.867848
                           2.4738329   0.1312843   2.8789136   9.1753482
                           15.350461   -5.867848   -1.016185   -1.201896
                            -1.24696   -1.054285   -1.234277
           9          40   2.3223877    9.763248   9        25.622673
                           3.2434776   0.2498328   7.5547096   15.702412
                           41.810227   14.377327   1.2822236   1.1141863
                           1.4240772   1.6388511   1.5110085
          10           4   0.8329091   8.8853025   10        3.0506412
                           1.1153518    0.200741   2.2878444   2.0583539
                           4.5212885   0.9493588   0.4490487   0.4218676
                           0.4420709   0.4705538   0.4446891
          11           4   1.6677068   9.1421686   11        8.4739993
                           2.1370026   0.1384222   2.5967266   6.4604571
                           11.115106   -4.473999   -1.015163   -1.206069
                           -1.250061   -1.052192   -1.237398
          12          11   1.6486586   8.8392767   12        6.6700046
                           1.8976206    0.215631   4.3892793    4.370999
                           10.178214   4.3299954   1.1805083   1.0306087
                           1.1284086    1.292533   1.1572363
          13           8   0.6931472   9.7413215   13        4.9445553
                            1.598287   0.2421072   3.5679541   3.0764172
                           7.9471104   3.0554447   1.0375394   0.9162945
                           1.0219727   1.1572009   1.0498675
          14           3   1.6094379   9.5334378   14        10.626556
                           2.3633562   0.1756432   2.2556765   7.5315572
                           14.993406   -7.626556   -1.445294    -1.90413
                           -2.055127   -1.559906   -1.992522
          15           3   0.6931472   9.0300168   15        2.9472129
                           1.0808599    0.159939   2.0447194   2.1541264
                           4.0322906   0.0527871   0.0255406   0.0254415
                           0.0261383   0.0262401   0.0261436
          16           1   1.2809338    9.289244   16        6.4058856
                           1.8572172   0.1316801   1.8893305   4.9487203
                           8.2921176   -5.405886   -1.519153   -2.107524
                           -2.169129   -1.563559   -2.139754

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                     TOTAL CRASHES negbin AFTER ONLY

                           The GENMOD Procedure

                        Observation Statistics

 Observation     CRASHTOT      logYEARBA         logDEV   SITEID          Pred
                                   Xbeta            Std     HessWgt      Lower
                                   Upper         Resraw      Reschi     Resdev
                                StResdev       StReschi      Reslik

          17           5   1.1631508   9.2119391   17        5.3827531
                              1.6832   0.1317704   2.8615843   4.1575866
                           6.9689543   -0.382753   -0.122262   -0.124434
                           -0.127664   -0.125436   -0.127554
          18          10   1.1631508   9.3831165   18        6.0965329
                           1.8077202   0.1417445   4.1340786   4.6177431
                           8.0488915   3.9034671   1.1380925    0.996976
                           1.0319712   1.1780412   1.0423471

--------------------------------------------------------------------------

                 Values of CRASHTOT, Pred, Xbeta, and Std

              CRASHTOT          Pred         Xbeta          Std

                     9     15.949406     2.7694216     0.140913
                    10     10.705211     2.3707306    0.1487304
```

```
                     2    1.7110786    0.5371239    0.3518995
                     4    1.8945099    0.6389602    0.2748077
                     4    3.0998013     1.131338    0.1452407
                    22    18.471046    2.9162044    0.1315558
                    18    21.104663     3.049494    0.1328175
                     6    11.867848    2.4738329    0.1312843
                    40    25.622673    3.2434776    0.2498328
                     4    3.0506412    1.1153518     0.200741
                     4    8.4739993    2.1370026    0.1384222
                    11    6.6700046    1.8976206     0.215631
                     8    4.9445553     1.598287    0.2421072
                     3    10.626556    2.3633562    0.1756432
                     3    2.9472129    1.0808599     0.159939
                     1    6.4058856    1.8572172    0.1316801
                     5    5.3827531       1.6832    0.1317704
                    10    6.0965329    1.8077202    0.1417445

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                     INJURY CRASHES negbin AFTER ONLY

                           The GENMOD Procedure

                            Model Information

   Data Set                     WORK.WORK1
   Distribution          Negative Binomial
   Link Function                       Log
   Dependent Variable             CRASHINJ    CRASHINJ
   Offset Variable               logYEARBA


                 Number of Observations Read          18
                 Number of Observations Used          18


                         Class Level Information

   Class       Levels    Values

   SITEID          18    1 2 3 4 5 6 7 8 9 11 12 13 14 15 16 17 18 19


                  Criteria For Assessing Goodness Of Fit

       Criterion                 DF           Value        Value/DF

       Deviance                  16         20.6072          1.2879
       Scaled Deviance           16         20.6072          1.2879
       Pearson Chi-Square        16         29.8231          1.8639
       Scaled Pearson X2         16         29.8231          1.8639
       Log Likelihood                      -11.2776


Algorithm converged.


                     Analysis Of Parameter Estimates

                               Standard   Wald 95% Confidence      Chi-
  Parameter    DF   Estimate      Error          Limits          Square

  Intercept     1   -21.0032     8.6458   -37.9486    -4.0578      5.90
  logDEV        1     2.1703     0.9270     0.3535     3.9872      5.48

                          Analysis Of Parameter
                                Estimates

                         Parameter    Pr > ChiSq
```

```
                         Intercept        0.0151
                         logDEV           0.0192

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                     INJURY CRASHES negbin AFTER ONLY

                           The GENMOD Procedure

                     Analysis Of Parameter Estimates

                               Standard    Wald 95% Confidence      Chi-
  Parameter     DF    Estimate      Error          Limits         Square

  Dispersion     1      0.1204      0.2417    -0.1429     0.5940

                          Analysis Of Parameter
                                Estimates

                         Parameter    Pr > ChiSq

                         Dispersion

NOTE: The negative binomial dispersion parameter was estimated by maximum
      likelihood.

--------------------------------------------------------------------------

                     INJURY CRASHES negbin AFTER ONLY

                           The GENMOD Procedure

                            Model Information

   Data Set                      WORK.WORK1
   Distribution           Negative Binomial
   Link Function                        Log
   Dependent Variable              CRASHINJ    CRASHINJ
   Offset Variable                logYEARBA


                 Number of Observations Read          18
                 Number of Observations Used          18


                         Class Level Information

   Class       Levels    Values

   SITEID          18    1 2 3 4 5 6 7 8 9 11 12 13 14 15 16 17 18 19


                  Criteria For Assessing Goodness Of Fit

       Criterion                 DF           Value        Value/DF

       Deviance                  16         20.6072          1.2879
       Scaled Deviance           16         20.6072          1.2879
       Pearson Chi-Square        16         29.8231          1.8639
       Scaled Pearson X2         16         29.8231          1.8639
       Log Likelihood                      -11.2776


Algorithm converged.


                     Analysis Of Parameter Estimates
```

```
                               Standard   Wald 95% Confidence      Chi-
 Parameter    DF    Estimate      Error          Limits          Square

 Intercept     1    -21.0032     8.6458    -37.9486    -4.0578      5.90
 logDEV        1      2.1703     0.9270      0.3535     3.9872      5.48

                          Analysis Of Parameter
                                Estimates

                         Parameter    Pr > ChiSq

                         Intercept        0.0151
                         logDEV           0.0192

--------------------------------------------------------------------------

                     INJURY CRASHES negbin AFTER ONLY

                           The GENMOD Procedure

                     Analysis Of Parameter Estimates

                               Standard   Wald 95% Confidence      Chi-
 Parameter    DF    Estimate      Error          Limits          Square

 Dispersion    1      0.1204     0.2417     -0.1429     0.5940

                          Analysis Of Parameter
                                Estimates

                         Parameter    Pr > ChiSq

                         Dispersion

NOTE: The negative binomial dispersion parameter was estimated by maximum
      likelihood.


                          Observation Statistics

Observation    CRASHINJ    logYEARBA      logDEV   SITEID        Pred
                               Xbeta         Std    HessWgt       Lower
                               Upper      Resraw     Reschi      Resdev
                            StResdev    StReschi     Reslik

          1           1    2.3125354   9.1251092   1        3.0458987
                            1.113796   0.2773055   1.8271454   1.7687748
                           5.2451554   -2.045899   -1.002768   -1.212912
                           -1.326118   -1.096361   -1.291363
          2           7    1.2809338   9.5891877   2        2.9724769
                           1.0893956   0.3212197   2.9708291   1.5837833
                           5.5788052   4.0275231    2.004757   1.6260544
                           1.8727039   2.3088503   1.9889173
          3           3    1.9459101   9.0810286   3        1.9184192
                           0.6515015   0.3060224   1.7233651   1.0530689
                           3.4948634   1.0815808   0.7038378   0.6394851
                           0.6897891   0.7592039   0.6999601
          4           0    0.5596158   8.4661104   4        0.1262659
                           -2.069365   0.8219098   0.1225135   0.0252159
                           0.6322617   -0.126266   -0.352669   -0.500632
                           -0.523844   -0.369021   -0.512282
          5           1    0.5128236   8.6704292   5        0.1877358
                           -1.672719   0.6403941   0.2011402    0.053511
                           0.6586453   0.8122642    1.853836   1.2828142
                           1.3350966    1.929391   1.3897676
          6           1    0.6931472   9.0994088   6        0.5704267
                           -0.561371   0.2936989   0.5596035   0.3207768
                            1.014371   0.4295733   0.5501956   0.4930891
                           0.5043491   0.5627596   0.5070701
```

```
--------------------------------------------------------------------------

                     INJURY CRASHES negbin AFTER ONLY

                           The GENMOD Procedure

                        Observation Statistics

 Observation    CRASHINJ   logYEARBA      logDEV   SITEID        Pred
                               Xbeta         Std     HessWgt       Lower
                               Upper      Resraw      Reschi      Resdev
                            StResdev    StReschi      Reslik

           7           2   2.3418058   9.2866531   7        4.4534051
                            1.493669   0.2098863   2.3418552   2.9514584
                            6.719667   -2.453405   -0.938037   -1.095228
                            -1.16889   -1.001127   -1.149724
           8           4    2.541602   9.1952267   8        4.4595165
                           1.4950403   0.2390254   2.7973988   2.7914445
                           7.1243712   -0.459516   -0.175529   -0.179789
                           -0.195748    -0.19111    -0.19503
           9           1   1.9459101   9.2227629   9        2.6093755
                           0.9591109    0.227336   1.6929669   1.6711977
                            4.074228   -1.609375   -0.869114   -1.025026
                           -1.078536   -0.914485   -1.063767
          10           3   0.8329091   8.8853025   11       0.4121826
                           -0.886289   0.4564651   0.5092404    0.168479
                           1.0084013   2.5878174    3.934359   2.4560464
                           2.5629407   4.1055938   2.7219265
          11           1   1.6677068   9.1421686   12       1.6586296
                           0.5059917   0.2670427    1.291228   0.9827483
                           2.7993458    -0.65863   -0.466917   -0.510645
                           -0.536395   -0.490462   -0.532259
          12           0   1.6486586   8.8392767   13       0.8433018
                            -0.17043   0.4948698   0.6950372   0.3197047
                            2.224421   -0.843302   -0.874979   -1.267433
                           -1.406745   -0.971154   -1.335642
          13           3   0.6931472   9.7413215   14       2.2974246
                           0.8317888    0.438581   1.9189577    0.972569
                           5.4270289   0.7025754   0.4102563   0.3876095
                           0.4923072   0.5210712   0.5034343
          14           3   1.6094379   9.5334378   15       3.6579554
                           1.2969044   0.2836613   2.4000581   2.0979035
                           6.3780998   -0.657955   -0.286649   -0.298827
                           -0.338467   -0.324673   -0.335474
          15           1   0.6931472   9.0300168   16       0.4906748
                           -0.711974   0.3423496   0.4901308   0.2508333
                           0.9598474   0.5093252   0.7065413   0.6134869
                            0.630376   0.7259922    0.635791
          16           0   1.2809338    9.289244   17       1.5502561
                           0.4384202   0.2095015    1.101013   1.0281949
                           2.3373915   -1.550256   -1.143007    -1.68607
                           -1.734314   -1.175712    -1.70841

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                     INJURY CRASHES negbin AFTER ONLY

                           The GENMOD Procedure

                        Observation Statistics

 Observation    CRASHINJ   logYEARBA      logDEV   SITEID        Pred
                               Xbeta         Std     HessWgt       Lower
                               Upper      Resraw      Reschi      Resdev
                            StResdev    StReschi      Reslik

          17           1   1.1631508   9.2119391   18       1.1651623
```
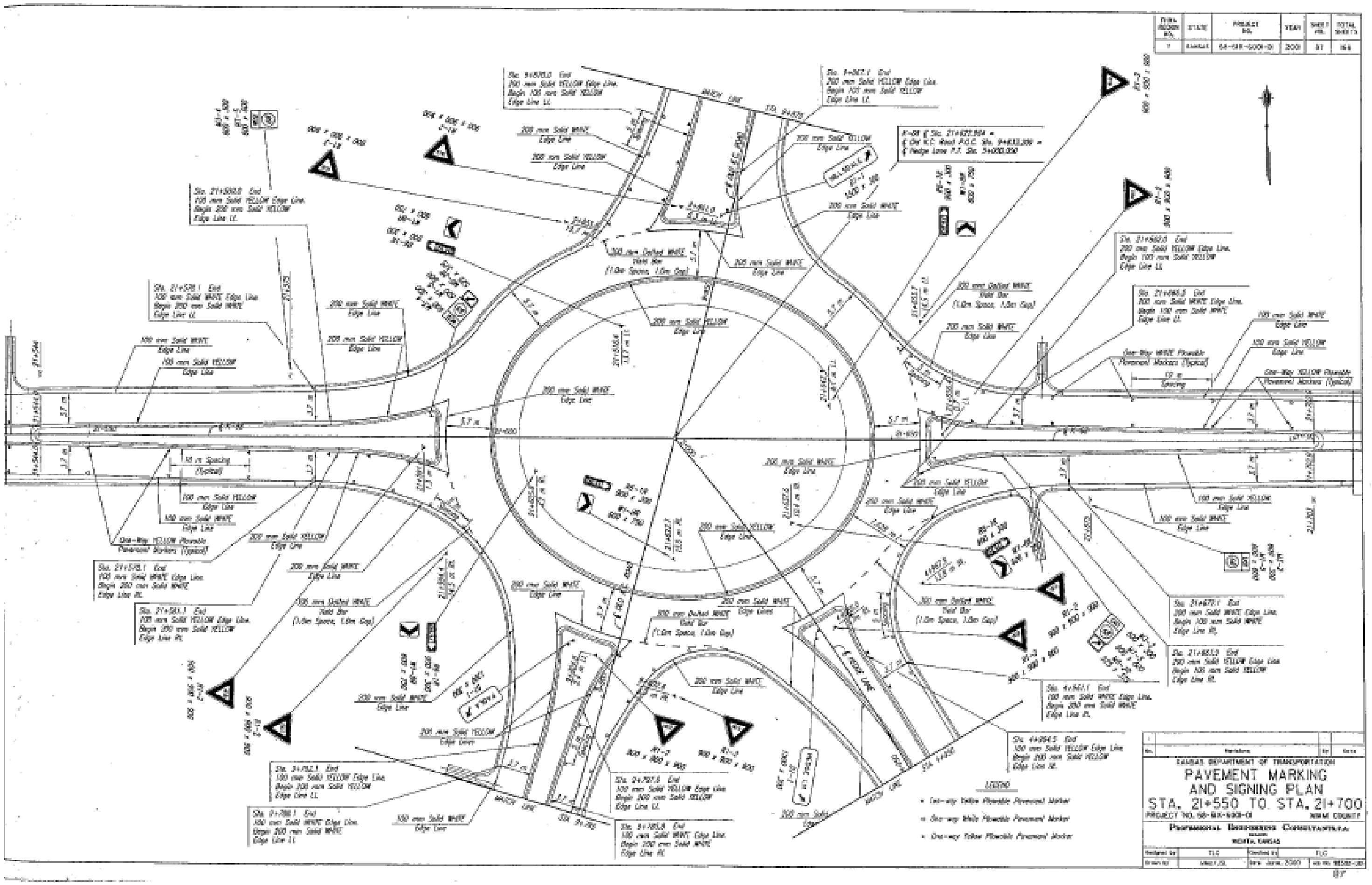
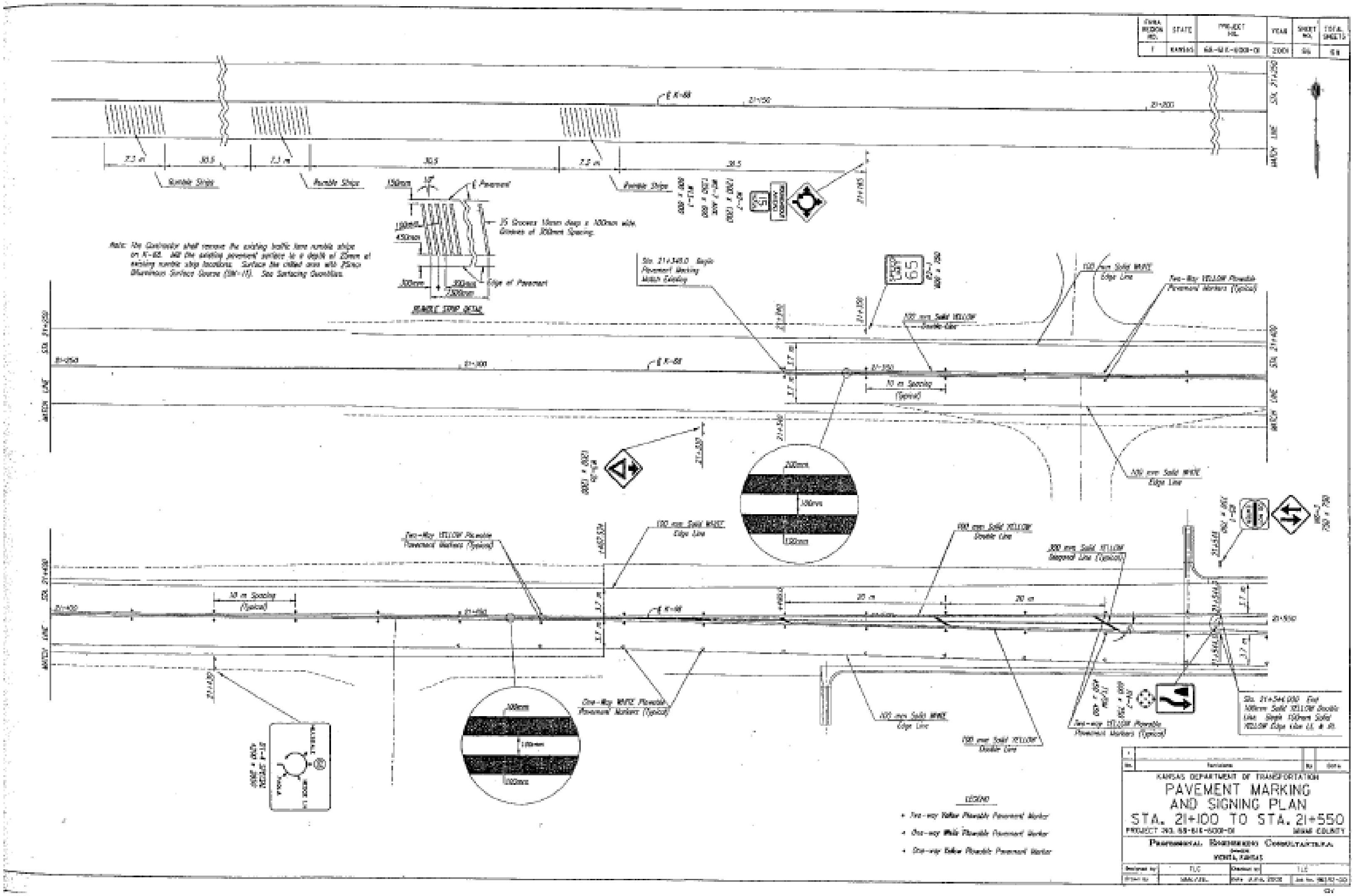

```
                           0.1528604   0.2316658   1.0040323   0.7399325
                           1.8347663   -0.165162   -0.143291   -0.147334
                           -0.151297   -0.147145   -0.151085
          18           1   1.1631508   9.3831165   19        1.689396
                           0.5243711   0.2140672   1.3070968   1.1104964
                            2.570075   -0.689396   -0.483512    -0.53045
                           -0.548572    -0.50003   -0.545549

--------------------------------------------------------------------------

                 Values of CRASHINJ, Pred, Xbeta, and Std

              CRASHINJ         Pred        Xbeta          Std

                     1    3.0458987     1.113796    0.2773055
                     7    2.9724769    1.0893956    0.3212197
                     3    1.9184192    0.6515015    0.3060224
                     0    0.1262659    -2.069365    0.8219098
                     1    0.1877358    -1.672719    0.6403941
                     1    0.5704267    -0.561371    0.2936989
                     2    4.4534051     1.493669    0.2098863
                     4    4.4595165    1.4950403    0.2390254
                     1    2.6093755    0.9591109     0.227336
                     3    0.4121826    -0.886289    0.4564651
                     1    1.6586296    0.5059917    0.2670427
                     0    0.8433018     -0.17043    0.4948698
                     3    2.2974246    0.8317888     0.438581
                     3    3.6579554    1.2969044    0.2836613
                     1    0.4906748    -0.711974    0.3423496
                     0    1.5502561    0.4384202    0.2095015
                     1    1.1651623    0.1528604    0.2316658
                     1     1.689396    0.5243711    0.2140672
```

# APPENDIX G.  EXAMPLE ADVANCED SIGNING PLANS





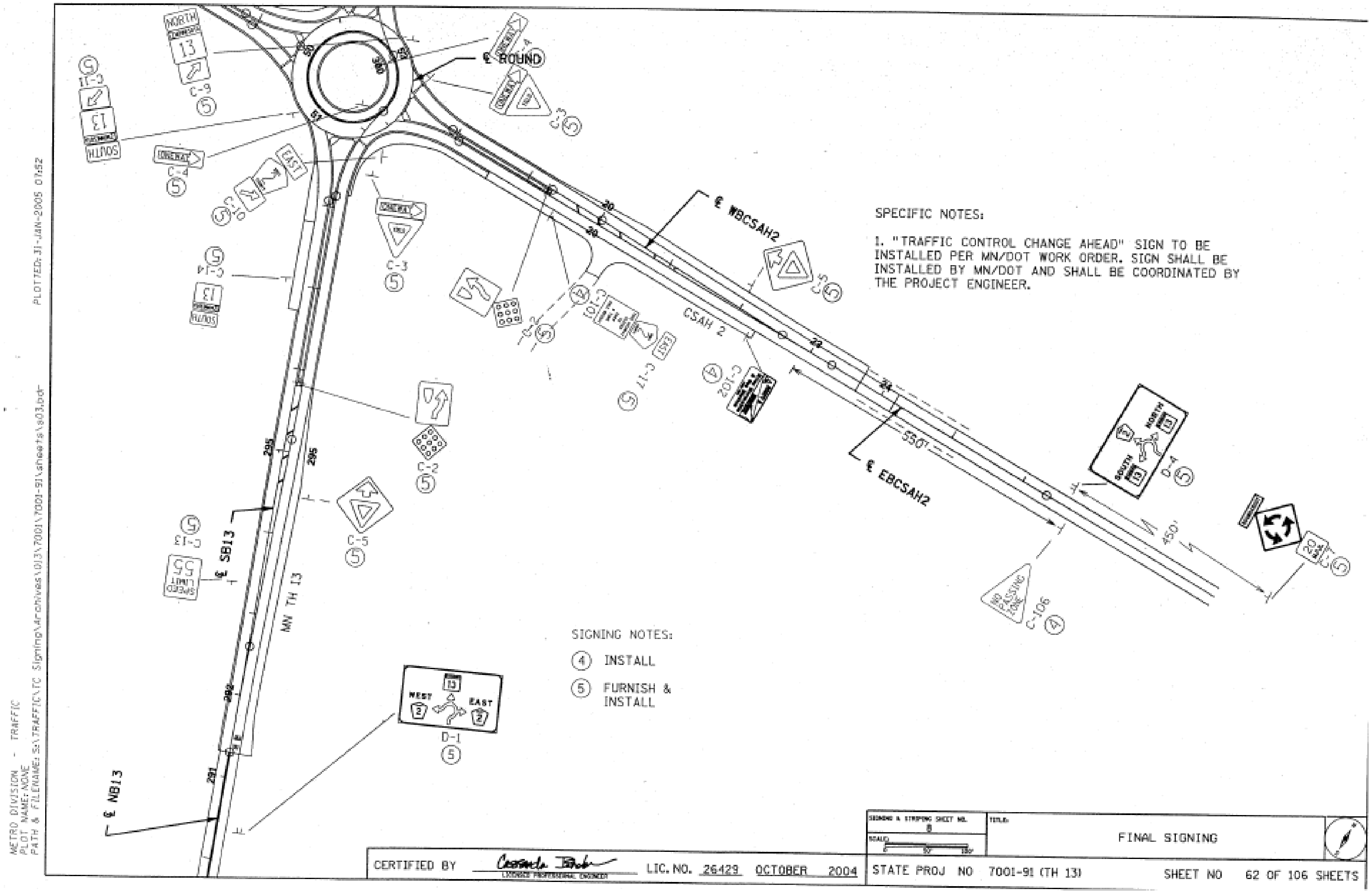
KANSAS DEPARTMENT OF TRANSPORTATION

PAVEMENT MARKING
AND SIGNING PLAN
STA. 21+100 TO STA. 21+550

PROJECT NO. 68-61X-6000-01

PROFESSIONAL ENGINEERING CONSULTANTS, P.A.
WICHITA, KANSAS

Designed by TLC
Checked by TLC



SPECIFIC NOTES:

1. "TRAFFIC CONTROL CHANGE AHEAD" SIGN TO BE INSTALLED PER MN/DOT WORK ORDER. SIGN SHALL BE INSTALLED BY MN/DOT AND SHALL BE COORDINATED BY THE PROJECT ENGINEER.

SIGNING NOTES:

④ INSTALL

⑤ FURNISH & INSTALL

CERTIFIED BY Cassandra Isackson LICENSED PROFESSIONAL ENGINEER LIC. NO. 26429 OCTOBER 2004

SIGNING & STRIPING SHEET NO. 8

SCALE: 0 50' 100'

TITLE: FINAL SIGNING

STATE PROJ NO 7001-91 (TH 13) SHEET NO 62 OF 106 SHEETS

# APPENDIX H. APPROACH ROAD TUBE LAYOUT PHOTOS

Rural Paola, KS (Photo Source: © 2011 Isebrands)

Rural Paola, KS  (Photo Source: © 2011 Isebrands)

Rural Paola, KS  (Photo Source: © 2011 Isebrands)

Rural Paola, KS  (Photo Source: © 2011 Isebrands)

Rural Florence, KS  (Photo Source: © 2011 Isebrands)

Rural Florence, KS  (Photo Source: © 2011 Isebrands)

# APPENDIX I. SPEED PROFILES