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Evaluation of Safety Performance of Rural Roundabouts

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Kansas Department of Transportation

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16 Abstract

This study evaluated the safety performance of rural roundabouts in Kansas using before-and-after analysis and comparison group approaches. Study results showed that the anticipated number of injury and fatal crashes significantly decreased after the implementation of isolated rural roundabouts. The before-and-after analysis indicated a reduction of 30 injury crashes and 5 fatal crashes over the study period, and the projected number of injury crashes decreased by 45.6%, which is statistically significant at the 0.05 level. A significant decrease in fatal crashes (33.33%) and fatal and injury crashes (44.62%) was also observed. After incorporating comparison groups into the research, injury crashes decreased by 26.3 and fatal crashes decreased by 4.2, while injury crashes decreased by 46.69%, with statistical significance at an alpha level of 0.07. The total number of fatal and injury crashes also decreased significantly at the 0.06 level. The evaluation of rural interchange roundabouts revealed 18 fewer expected injury crashes throughout the duration of the study, indicating a 68.33% decrease in the projected number of injury crashes. This reduction was significant at a 0.08 level of significance. With 94% confidence, this research indicates that rural roundabouts contribute to a decrease in the numbers of fatal and injury crashes. In addition, a benefit-cost analysis of both approaches substantiated the economic value of isolated rural roundabouts, with a total benefit over 20 years of $509,487,883.63 using a straightforward before-after analysis and $429,540,426.09 using comparison groups; the calculated benefit-cost ratios were 11.16:1 and 9.41:1, respectively. Overall, the study results proved the efficacy of rural roundabouts for reducing traffic crashes and improving rural road safety in Kansas.

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THE KANSAS DEPARTMENT OF TRANSPORTATION
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PREFACE

The Kansas Department of Transportation's (KDOT) Kansas Transportation Research and New-Developments (K-TRAN) Research Program funded this research project. It is an ongoing, cooperative and comprehensive research program addressing transportation needs of the state of Kansas utilizing academic and research resources from KDOT, Kansas State University and the University of Kansas. Transportation professionals in KDOT and the universities jointly develop the projects included in the research program.

NOTICE

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Abstract

This study evaluated the safety performance of rural roundabouts in Kansas using before-and-after analysis and comparison group approaches. Study results showed that the anticipated number of injury and fatal crashes significantly decreased after the implementation of isolated rural roundabouts. The before-and-after analysis indicated a reduction of 30 injury crashes and 5 fatal crashes over the study period, and the projected number of injury crashes decreased by 45.6%, which is statistically significant at the 0.05 level. A significant decrease in fatal crashes (33.33%) and fatal and injury crashes (44.62%) was also observed. After incorporating comparison groups into the research, injury crashes decreased by 26.3 and fatal crashes decreased by 4.2, while injury crashes decreased by 46.69%, with statistical significance at an alpha level of 0.07. The total number of fatal and injury crashes also decreased significantly at the 0.06 level. The evaluation of rural interchange roundabouts revealed 18 fewer expected injury crashes throughout the duration of the study, indicating a 68.33% decrease in the projected number of injury crashes. This reduction was significant at a 0.08 level of significance. With 94% confidence, this research indicates that rural roundabouts contribute to a decrease in the numbers of fatal and injury crashes. In addition, a benefit-cost analysis of both approaches substantiated the economic value of isolated rural roundabouts, with a total benefit over 20 years of $509,487,883.63 using a straightforward before-after analysis and $429,540,426.09 using comparison groups; the calculated benefit-cost ratios were 11.16:1 and 9.41:1, respectively. Overall, the study results proved the efficacy of rural roundabouts for reducing traffic crashes and improving rural road safety in Kansas.

Acknowledgments

The authors would like to extend their appreciation to the Kansas Department of Transportation (KDOT), whose staff played a key role in the accomplishment of this study by supplying crash data, roundabout project information, and traffic volume statistics that served as the foundation of the investigation.

Additionally, the authors wish to express their gratitude to the Kansas Historical Society (KSHS). Their assistance in supplying older crash data for the state of Kansas was particularly beneficial.

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Chapter 1: Introduction

As an innovative intersection design, the use of roundabouts to improve road safety has drawn considerable interest in the field of transportation engineering. Roundabouts are circular crossroads that direct traffic flow in a counterclockwise direction and remove conflict areas in conventional signalized or stop-controlled junctions. They have become well known for their success in lowering crash severity and frequency (Retting et al., 2001).

In rural areas, these roundabouts are particularly effective at transition points where high-speed roads meet, providing a safer and more efficient alternative to traditional intersections controlled by stop signs or traffic signals. According to Fatality Analysis Reporting System (FARS), an urban area is defined by boundaries set by state and local officials and approved by the FHWA, U.S. DOT, following Title 23 of the USC. If not already established, boundaries for places with a population of 5,000 or more, designated by the Bureau of the Census, are used to define an urban area. In contrast, rural areas refer to regions that lack the population density, infrastructure, and economic base typically associated with urban areas. They are characterized by a greater abundance of natural landscapes compared to urban areas, lower population density, and can be more spread out geographically. Although roundabouts have been extensively researched in urban settings, their safety performance and effectiveness in rural settings remain relatively unexplored. Rural areas comprise a sizable portion of Kansas highways, so this study focused on the role of rural roundabouts for improving traffic safety in rural areas in Kansas. The assessment of roundabout performance in these settings is vital for rural road safety since crash rates are often higher in rural areas than in metropolitan areas (Zwerling et al., 2005).

1.1 Background

Although transportation safety is paramount for both urban and rural populations, factors such as low traffic numbers, high speed limits, and lengthy travel times for rural locations contribute to specific safety concerns. In addition, rural transportation systems also typically have fewer available emergency services and longer emergency response times. Therefore, determining practical safety countermeasures for rural locations is essential for lowering crash frequency and severity.

Roundabouts are circular crossroads in which incoming cars must yield to moving traffic as they circulate around a central island as shown in **Figure 1.1**. Due to their capacity to increase safety, decrease congestion, and improve traffic flow, roundabouts have become increasingly popular on a global scale. Urban regions primarily utilize roundabouts to decrease traffic delays, increase capacity, and improve traffic operations. Urban studies have repeatedly demonstrated that, compared to conventional intersection configurations, roundabouts minimize fatal and serious injury crashes. Roundabouts may also be helpful in rural locations, specifically for areas with conflict points and slow-moving traffic. However, further research is needed to determine how well roundabouts improve road safety in rural areas.

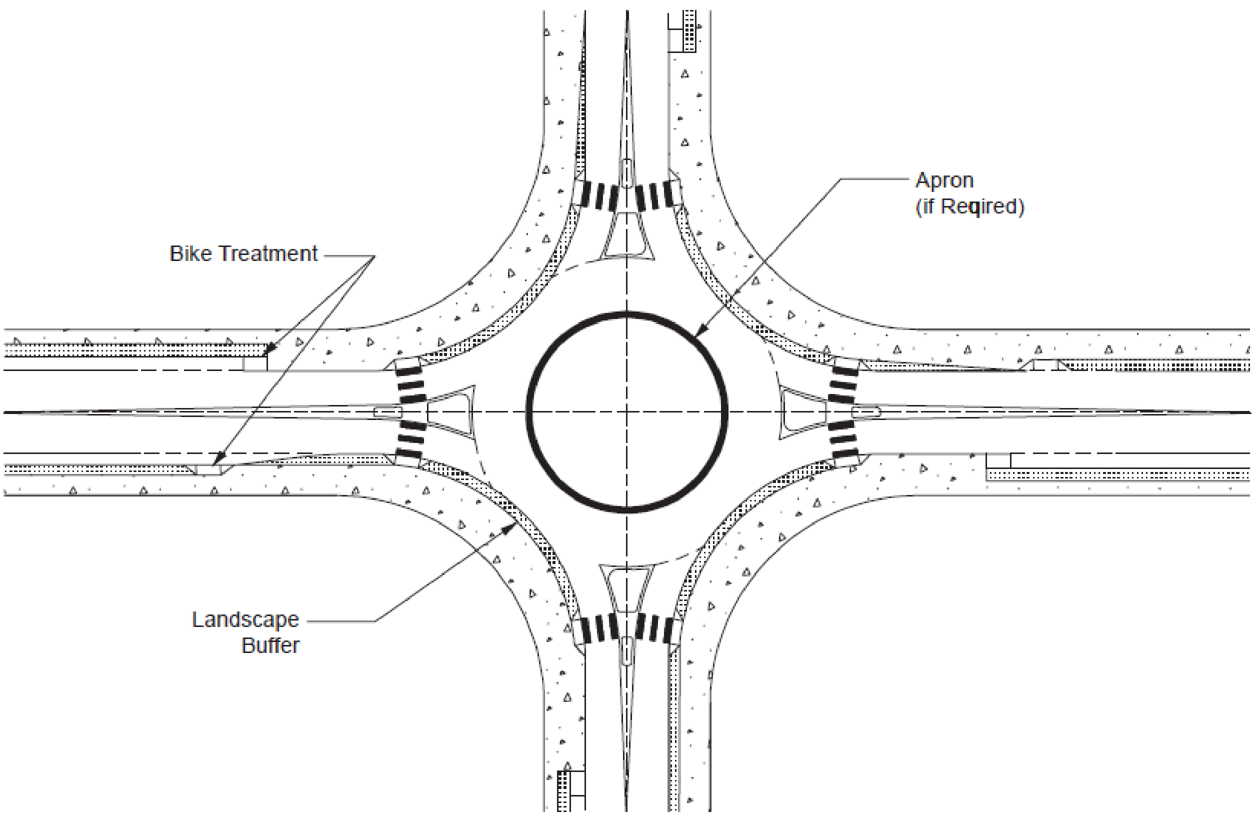

Figure 1.1: Single-Lane Roundabout
Source: American Association of State Highway and Transportation Officials (2018)

Rural roundabouts typically service areas that have lower traffic volumes than their urban counterparts and have increased vehicle approach speeds. Therefore, safety assessments of rural roundabouts are essential to ensure they effectively improve safety and reduce serious crashes. **Figure 1.2** shows the rural roundabouts opened each year in Kansas.

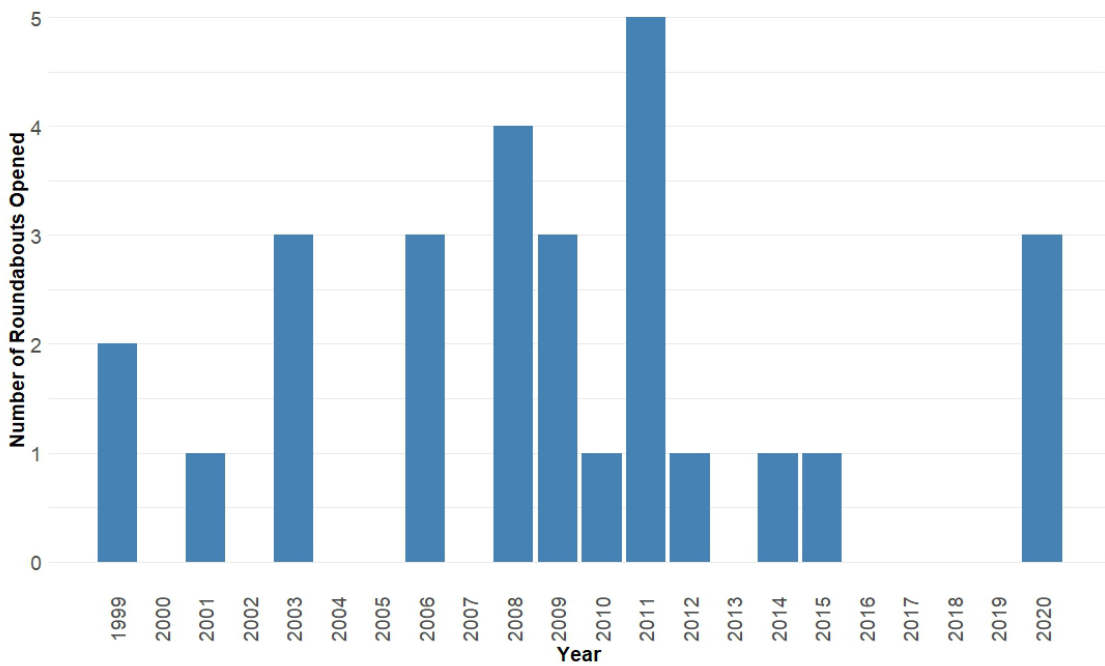

Figure 1.2: Rural Roundabouts Opened in Kansas

1.2 Research Objectives

The primary goal of this study was to assess how rural roundabouts in Kansas impact roadway safety. The study utilized comparison groups and a before-and-after study as well as a thorough benefit-cost analysis to determine the return on investment for roundabouts in rural areas. This research also aimed to assess crash frequency at rural roundabouts in Kansas and compare it with crash frequencies at conventional stop-controlled or signalized junctions in surrounding rural areas, thereby evaluating the overall safety performance of rural roundabouts.

To achieve these objectives, this research used a before-and-after study with comparison groups, which is a statistical method frequently used in transportation safety research. This method compares the observed crash frequency in treatment groups with the projected number of crashes in comparison groups, considering traffic volumes, geometric design elements, and historical crash data. This approach provides a thorough assessment of safety performance while accounting for potential biases and confounding factors. In addition to the safety assessment, this study conducted a thorough benefit-cost analysis to quantify safety benefits with building costs. Analysis results revealed the cost-effectiveness of roundabout projects in Kansas by contrasting the costs and benefits related to the installation of rural roundabouts.

1.3 Research Significance

This research report offers evidence on the usefulness of roundabouts in rural settings to help transportation authorities formulate suitable safety policies and guidelines. By accounting for both safety and economic factors, the benefit-cost analysis educates policymakers and practitioners as they determine infrastructure expenditures.

1.4 Organization of the Report

This report is structured into five chapters, following this introduction (Chapter 1). Chapter 2 includes a thorough literature analysis with a focus on roundabout safety effects, operating characteristics, and benefit-cost assessments for the context and history of the subject. Chapter 3 describes the methodology used in this study, including data collection, location selection, and statistical analysis techniques, as well as the before-and-after study approach to assess the effects of roundabouts on traffic safety. Chapter 4 presents the analysis results, including crash rates and severities before and after the implementation of roundabouts, and the benefit-cost analysis. Chapter 5 connects the findings to the research objectives and offers recommendations for further research.

Chapter 2: Literature Review

This literature review explores previous studies on the operational and safety characteristics of roundabouts, especially rural ones.

2.1 Roundabout Safety Effects for Drivers and Pedestrians

2.1.1 Driver Safety at Roundabouts

Numerous studies have compared roundabouts to conventional stop-controlled or signalized intersections to examine the safety implications of roundabouts on motorists. Gross et al. (2013) analyzed 28 sites throughout the United States and found that the use of roundabouts significantly reduces the numbers of fatal and injury crashes. They determined the crash modification factors (CMFs) for total and injury crashes to be 0.792 and 0.342, respectively, which indicated a significant reduction in crashes, especially in all levels of injury crashes. Similarly, Saccomanno et al. (2008) used a simulation study to determine that roundabouts significantly reduce the likelihood of rear-end conflicts compared to signalized intersections. Retting et al. (2001) studied 24 roundabouts in the United States and found a 39% reduction in total crashes and a 76% reduction in fatal and serious injury crashes compared to signalized intersections. Elvik (2003) performed a meta-analysis on the impact of converting intersections to roundabouts outside the United States and found a significant reduction in injury and fatal crashes, with a 30%–50% decrease in injury crashes and a 50%–70% decrease in fatal crashes. These reductions were attributed to some key design features of roundabouts: mandating yield on entry, lowering high-speed crash risks; and enforcing one-way travel around a central island, simplifying driving decisions and minimizing head-on and side-impact or angle crashes. Rodegerdts et al. (2010) also focused on the increased safety due to roundabouts because they eliminate conflict points associated with a standard intersection and they have significantly fewer conflict points than a typical intersection, as shown in **Figure 2.1**. The decrease in conflicts also reduces the number of conflicts that likely result in the most severe injuries, such as left-turn, head-on, and angle crashes.

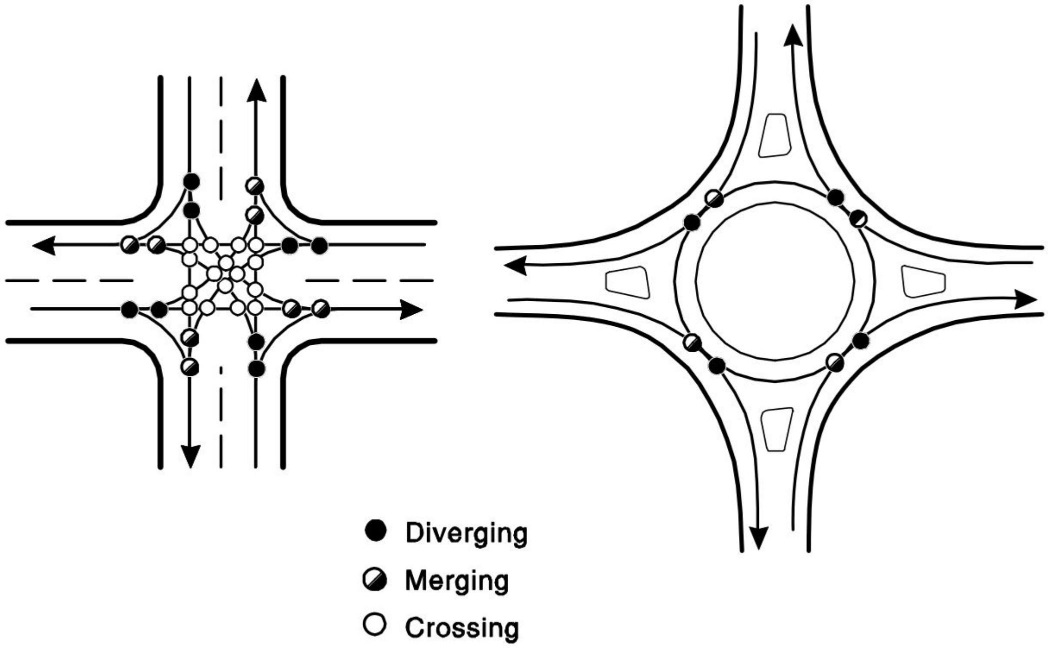

Figure 2.1: Roundabout Conflict Points
Source: Rodegerdts et al. (2010)

2.1.2 Pedestrian Safety at Roundabouts

Previous studies have highlighted the positive effects roundabouts have on pedestrian safety. For example, Zhou et al. (2022) compared roundabouts and signalized intersections via simulation and found that roundabouts exhibited lower rates of pedestrian-vehicle conflicts than signalized crossings. Bruede and Larsson (1999) studied pedestrian safety at roundabouts in Scandinavia and concluded that roundabouts, especially single-lane roundabouts, were typically safer for pedestrians than standard intersections. This is due to simpler vehicle paths and reduced speeds, which enhance driver awareness and ease of yielding to pedestrians. Stone et al. (2002) utilized speed as an indirect safety metric to show that pedestrian fatality risk decreased to 15% at roundabouts with typical speeds of 20 mph. In contrast, at standard signalized intersections with speeds of 30–40 mph, this risk increased to 45%–85%. Overall, research showed that roundabouts significantly lower the number of crashes and injuries, mainly due to lower speeds and fewer conflict points, benefiting both drivers and pedestrians.

2.2 Operational Characteristics of Roundabouts

An accurate understanding of the operational characteristics of roundabouts is crucial for evaluating their safety performance. Previous studies have examined operational factors such as entry capacity, circulating capacity, and queuing behavior at roundabouts to increase understanding of roundabout safety.

2.2.1 Entry Capacity

Polus and Shmueli (1997) identified several key benefits of roundabouts. First, they establish a smooth, one-way flow around the central island, with clear priorities and predictable wait times. Second, they enhance safety by providing a clear priority system that requires vehicles to slow down due to the deflection angles at the entries, which naturally guide vehicles into a curved path, reducing their speed before entering the roundabout. Additionally, roundabouts contain fewer conflict points with crossing traffic streams, further improving safety compared to traditional four-way intersections. Roundabout design is particularly effective for intersections with four or more approaches because it reduces driver confusion and delays, and roundabouts allow for future enhancements or construction (e.g., expansion of traffic lanes, integration of pedestrian and bicycle path etc.) as well as increased space for traffic. Polus and Shmueli (1997) analyzed the entry capacities of small and medium-sized roundabouts (having the diameter between about 15 to 60 m), focusing on the efficiency of roundabouts over conventional intersections for left turns. They observed that as circulating flow increases, the entry capacity decreases. However, they also found that roundabouts with larger diameters could increase capacity. Specifically, an increase in diameter from 30 to 60 m at minimum circulating flow can enhance capacity by up to 21%.

2.2.2 Queuing Behavior

Queuing behavior at roundabouts has been shown to negatively affect traffic flow and safety. Park et al. (2018) studied waiting behavior at roundabouts and found that queue lengths vary depending on traffic volume, lane configuration, and arrival patterns. Roundabout design and operation could be improved by observing queue behavior to identify potential safety issues.

2.2.3 Traffic Volume

Roundabouts may become less effective as traffic volume rises, leading to longer queues and lengthier delays. Chen et al. (2013) studied roundabout approaches in eight states in the United States and 34 roundabout approaches from three cities in Italy and found that roundabouts with the highest safety performance had traffic levels of 1,500–2,500 vehicles per hour. Similarly, Rodegerdts et al. (2007) found that roundabouts regulate traffic flow, thereby decreasing crash severity and travel speeds.

2.2.4 Geometric Design

Geometric design aspects such as roundabout diameter, lane configuration, and entry and exit angles have been shown to significantly influence roundabout safety. Flannery (2001) concluded that crashes often occur at rural roundabouts in the United States due to excessive speeds and unexpected driver behavior (e.g. drivers speeding on entry, cutting across multiple lanes to exit, and incorrectly entering roundabouts to proceed clockwise.) as well as design issues such as unbalanced flows, limited sight distance, and low volume-to-capacity (v/c) ratios that exacerbate operational challenges. Their study results could help designers refine roundabout designs to mitigate identified issues.

To maximize safety, the operational qualities of roundabouts in rural Kansas must be modified based on local conditions, vehicle types, and traffic volume. Hallmark et al. (2010) found that effective roundabout designs in rural locations must accommodate heavy vehicles such as trucks and agricultural machinery.

The operational characteristics of roundabouts can be used to improve their design and operation by illuminating variables related to safety performance, such as entry and circulating capacity, queuing behavior, and geometric design features like diameter, lane configuration, and entry and exit angles. These factors influence traffic flow efficiency, congestion management, and driver behaviors, critical for identifying and addressing safety issues.

2.3 Before-and-After Traffic Safety Study

Before-and-after studies are essential for assessing the impact of interventions on road safety. Hauer (1997) determined that evaluation of the efficacy of interventions and changes to traffic systems, such as modifications to road design or the adoption of new traffic legislation, is the essence of before-and-after studies. In another study, Lord et al. (2021) described the theoretical foundation and procedures of a before-and-after study for highway safety analytics and modeling.

2.3.1 Before-and-After Study Methods

Before-and-after studies typically collect data on specific measures before and after the implementation of an intervention (Persaud & Lyon, 2007). As noted by Lord et al. (2021), a key challenge of before-and-after studies is accounting for confounding variables that could affect outcome measures. Therefore, complex before-and-after study designs, such as the Empirical Bayes (EB) technique that integrates real crash data with anticipated crash frequencies, have been created to account for regression to the mean, variations in traffic volume, and long-term patterns, resulting in more accurate estimates (Mountain et al., 1998).

2.3.2 Before-and-After Study Applications

Numerous before-and-after studies have assessed traffic safety initiatives. For example, Elvik (2003) used before-and-after studies to evaluate the safety impacts of roundabouts and discovered a substantial decline in crash rates. Similarly, Shirazinejad et al. (2018) utilized before-and-after study to find out the effect of increased speed limits in Kansas and found that increasing the speed limit from 70 mph to 75 mph resulted in a 27% increase in total crashes and a 35% increase in fatal and injury crashes. The work of Lord et al. (2021) also offers numerous examples of before-and-after studies for evaluating various safety solutions, such as speed bumps, coordinated traffic signals, and enhancements to highway safety. Persaud et al. (2001) found that crash rates and crash severity were significantly lower when roundabouts replaced traditional intersections.

2.3.3 Limitations and Challenges

Despite their frequent use, before-and-after studies are plagued by short data collection periods, a dearth of control groups, and inadequate accounting of regression to the mean, according to Hauer et al. (2002). Lord et al. (2021) also identified difficulty in selecting appropriate comparison locations and data quality as challenges of these studies. Although before-and-after studies are important for evaluating traffic safety measures, their limitations and potential influencing factors such as seasonal and spatial variations, traffic volume changes, etc., must be considered to ensure reliable and accurate results.

2.4 Benefit-Cost Analysis

Benefit-cost analysis is a valuable tool for assessing the economic feasibility and effectiveness of transportation projects, including roundabouts. In terms of the expenses incurred during design, building, and maintenance, this analysis helps quantify the resulting savings due to increased safety and operational performance. Rouphail et al. (2001) evaluated the benefit-cost ratio of roundabouts compared to signalized intersections and found that roundabouts outweighed initial construction costs by advantageously reducing crashes and travel time. Similarly, a study by Bezerra et al. (2010) investigated the benefit-cost ratio of roundabouts in Brazil and determined that roundabouts provide significant financial advantages, such as lower crash costs, decreased travel times, and reduced operational expenses for vehicles. Their results also indicated an approximate 50% decrease in both crash incidents and severity. Flannery and Datta (1996) found that roundabouts outperform other forms of crossings in terms of lifetime expenses and the decrease in collisions that resulted in injuries and deaths generated sizable societal savings.

2.5 Conclusion

The literature review highlighted key findings regarding the safety effects of roundabouts for drivers and pedestrians, operating characteristics of roundabouts, and the use of before-and-after studies in traffic safety. The review also described the significance of benefit-cost analysis in traffic safety analysis studies. Although roundabouts were shown to generally increase driver and pedestrian safety, their operating characteristics must be considered to maximize effectiveness. The before-and-after research offers a strong statistical method for assessing roundabout safety, and the benefit-cost analysis reveals the cost-effectiveness of roundabout implementation. Despite high initial expenses, roundabouts demonstrate long-term cost-effectiveness due to decreased maintenance costs and a decline in crash rates.

Chapter 3: Methodology

Following the methodological criteria outlined in Lord et al. (2021), this study utilized the before-and-after design with comparison groups. This chapter describes the data collection, statistical analysis, location selection for the study, and study design as well as the principles of benefit-cost analysis.

3.1 Study Site Selection

The Kansas Department of Transportation (KDOT) initially provided a list of 130 roundabouts in Kansas, including roundabout details such as overall geometry, opening timeline, and previous traffic control systems. Twenty-eight (28) of the 130 locations were chosen for analysis because they are situated in rural settings and had available data like construction costs and project numbers. Each of the 28 sites was categorized as either a conventional roundabout (isolated rural areas) or a roundabout on a rural interchange. A total of 12 locations comprised the first group, while 16 sites made up the second group. These two groups were analyzed separately due to their unique operational natures. **Table 3.1** and **Figure 3.1** highlight conventional roundabouts, while **Table 3.2** and **Figure 3.2** focus on roundabouts at rural interchanges.

Isolated Kansas intersections that were not transformed into roundabouts were chosen as comparison sites. To account for potential confounding factors (e.g., intersection type and location), the comparison sites were matched to roundabout sites based primarily on annual average daily traffic (AADT). A total of 24 comparison sites were selected. The whole list of these sites can be found in **Appendix A**.

Table 3.1: Selected Rural Roundabout Sites

No.	Intersection	County	Latitude	Longitude	Year Opened
1	N. Jct. of US-59 & US-169	Anderson	38.258322	-95.248646	2006
2	US400/US-69 Alternate/K-66/Beasley	Cherokee	37.075722	-94.716222	2008
3	East Jct. US-77 & US-166	Cowley	37.07787	-97.0245	2009
4	US-59/US-160	Labette	37.193455	-95.267809	2020
5	US-50 & US-77	Marion	38.243915	-96.936594	2006
6	US-56/US-77/K-150	Marion	38.362833	-96.96675	2015
7	K-68 & Old Kansas City Rd/Hedge Lane	Miami	38.621342	-94.855491	2001
8	US-75/K-31/K-268	Osage	38.637833	-95.684705	2011
9	K-18 and Karns	Riley	39.030148	-96.882273	2020
10	US-50/K-281	Stafford	37.955882	-98.747004	2020
11	East Jct. US-81 & US-160 (15th/16th/A Streets)	Sumner	37.274911	-97.394099	2011
12	US-400 and K-47	Wilson	37.529934	-95.801793	2009

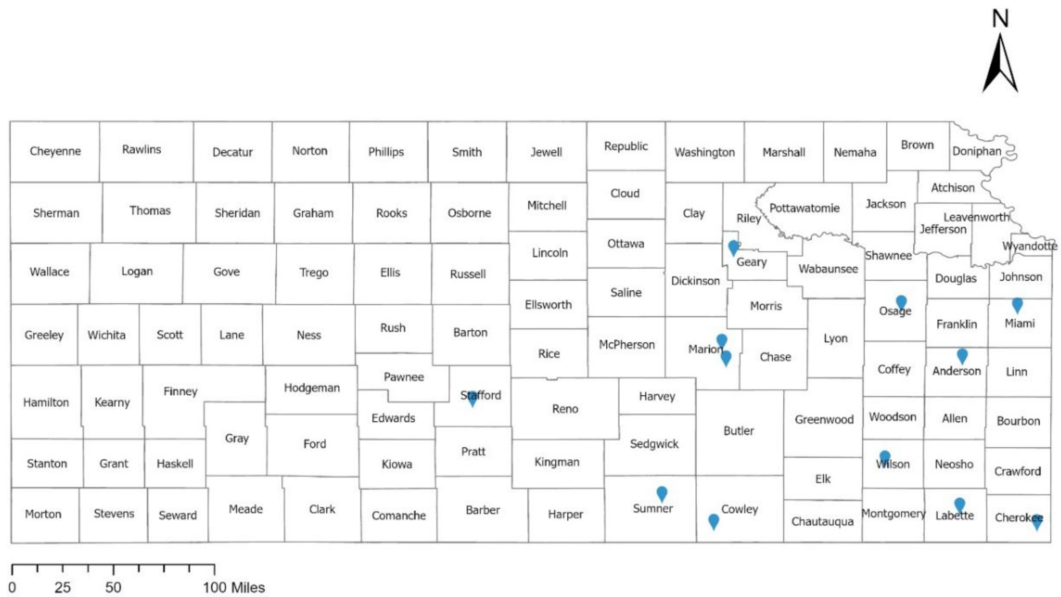

Figure 3.1: Location of Rural Roundabouts Selected for the Study

Table 3.2: Selected Rural Interchange Roundabout Sites

No.	Intersection	County	Latitude	Longitude	Year Opened
1	I-70 & Exit 202	Douglas	38.990722	-95.257278	2008
2	I-70 & Exit 204	Douglas	38.994583	-95.229583	2010
3	I-70 WB Ramps & US-40B (Washington St.)	Geary	39.008432	-96.835082	2006
4	I-70 WB Ramps & Chestnut/East Streets	Geary	39.021806	-96.816611	2009
5	I-135 & Broadway (New Interchange)	Harvey	38.050062	-97.32252	2003
6	I-135 & 1st Street (New Interchange)	Harvey	38.04253	-97.322506	2003
7	US-50 & Anderson (Interchange)	Harvey	38.026443	-97.354957	2014
8	K-7 & Johnson Dr/55th Street (Interchange)	Johnson	39.029004	-94.852645	2011
9	I-35 & US-50 Connector (Interchange)	Lyon	38.414953	-96.229223	2008
10	US-50 Connector & US-50 (Interchange)	Lyon	38.41224	-96.229482	2008
11	K-18 and Scenic Drive	Riley	39.155441	-96.644239	2012
12	I-70 EB & Rice Rd/Cyprus Drive	Shawnee	39.031805	-95.623229	1999
13	I-70 WB & Rice Rd./Sycamore Drive	Shawnee	39.036081	-95.623116	1999
14	US-75 & 46th Street	Shawnee	39.129361	-95.719667	2003
15	KTA Roundabout to Casino NB I-35	Sumner	37.471992	-97.321039	2011
16	KTA Roundabout to Casino SB I-35	Sumner	37.47133	-97.324451	2011

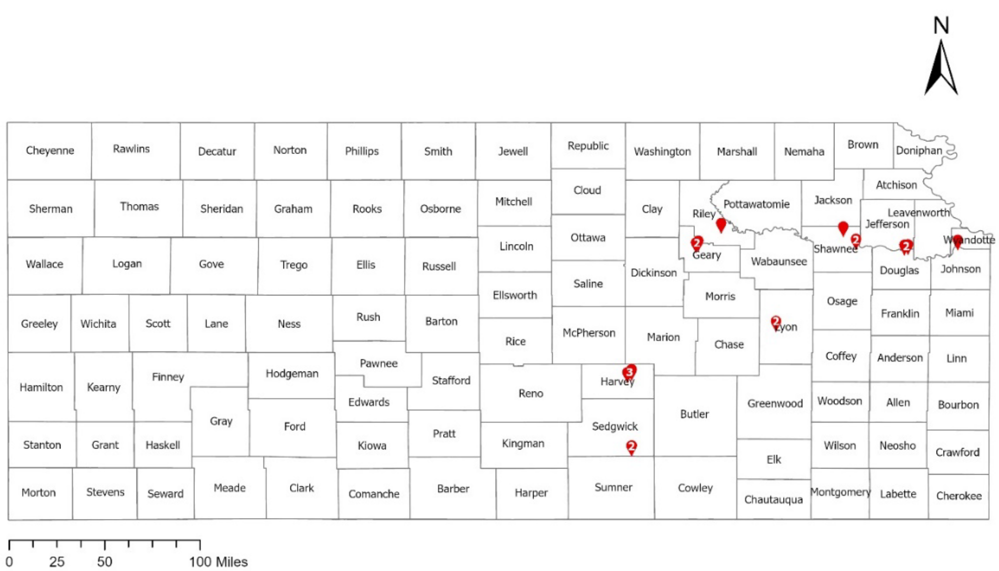

Figure 3.2: Location of Rural Interchange Roundabouts Selected for the Study (Numbers Indicate Multiple Sites in an Area)

3.2 Data Collection

Data collection for the study was comprised of crash data and traffic volume data.

3.2.1 Crash Data Collection

Crash data from 2000 to 2022 were collected from KDOT crash records, including crash date, crash severity, at-road and on-road location, and latitude and longitude information of the crash. The dataset also included lighting and weather conditions. Data were collected for three years before the opening of each roundabout and three years after the opening. The Kansas Historical Society (KSHS) provided roundabout crash data from 1994 to 1999.

3.2.2 Volume Data Collection

AADT data for the study sites was obtained from KDOT staff and traffic count maps. These data helped normalize the crash data and control for any changes in traffic volume over the study period. As an example, **Figure 3.3** shows 2022 AADT data from southeast Kansas.

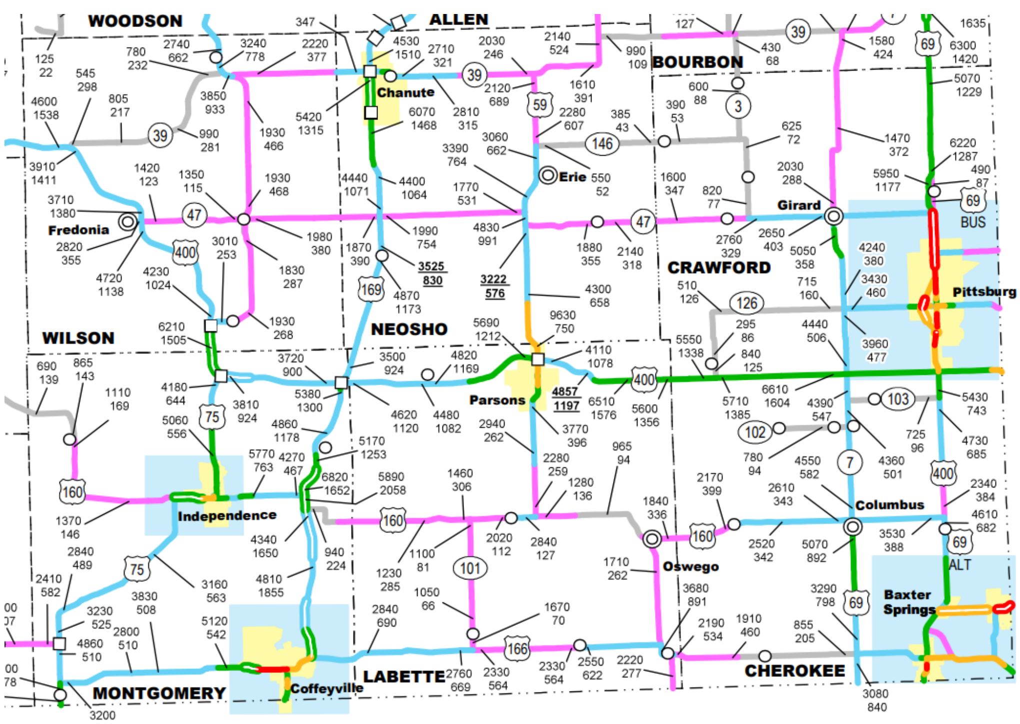

Figure 3.3: Map of 2022 AADT for Southeast Counties of Kansas
Source: KDOT (2023, June)

3.3 Before-and-After Study Design with Comparison Groups

The before-and-after study with comparison groups is a robust study design that provides a mechanism to control various confounding factors, such as regression to the mean and changes in traffic volume (Lord et al., 2021). The methodology compares the number of crashes at treatment locations to the number of crashes at comparison sites with similar pre-roundabout conditions over the same periods. The comparison sites serve as a control group to account for time trends and other systemic safety changes (e.g., changes in traffic regulations, public safety campaigns, technological advancements, etc.) that influence study sites without roundabouts. Specifically, before-and-after studies compare the predicted value with no treatment or change implementation to the estimated number of crashes after implementation (i.e., actual number of observed crashes) for a specific crash type (e.g., right-angle, run-off-the-road, all crashes) and crash severity (e.g., fatal, incapacitating, non-incapacitating, or possible injuries, or property damage only [PDO]). Using the difference or ratio, known as the index, the following assessments were made (Hauer, 1997):

$$\delta = \pi - \lambda$$

Equation 3.1

$$\theta = \lambda / \pi$$

Equation 3.2

Where:

δ = the decrease in the anticipated number of crashes;

θ = the index or ratio between the estimated and anticipated numbers of crashes;

π = the expected number of target crashes of a specific entity in the after period with no treatment implementation; and

λ = the estimated number of target crashes of a specific entity in the after period.

In Equations 3.1 and 3.2, the estimated reduction and index, respectively, are based entirely on data collected at sites with one or more treatments/changes implemented; the estimate does not account for variables with a regional or highly global impact on crash risk. For example, external factors such as weather patterns, economic situations (e.g., growth, recessions, etc.), crash reportability levels, and whether an observation is part of the treatment group should all similarly impact the results.

The before-and-after research can be supplemented with control sites or observations (comparison group) that are not the focus of an improvement. According to Hauer (1997), the inclusion of comparison sites in before-and-after analysis relies on two assumptions: 1) external factors that affect safety identically change from the before to the after period for both groups, and 2) change in external factors identically affects the treatment and the comparison groups. Sites in the comparison group also should preferably share traits such as sample mean, sample variance, range of traffic flow, lane and shoulder widths, and the presence of crosswalks with sites in the treatment group to minimize variance in results. The ratio of the before and after periods in the comparison group was defined as r_c. **Table 3.3** lists the notation definitions and the totals of each group site to create the variables.

Table 3.3: Notation Definitions for Treatment and Comparison Groups

Period	Treatment Group	Comparison Group
Before	κ	μ
After	λ	ν

The ratios for the treatment and comparison groups were computed using the notations in **Table 3.3** as **Equations 3.3** and **3.4**, respectively (Hauer, 1997).

$$r_t = {\sum \pi}/{\sum \kappa}$$

Equation 3.3

$$r_c = {\sum \upsilon}/{\sum \mu}$$

Equation 3.4

Where:

$\pi = r_t\kappa$, and

r_t = the linear or nonlinear relationship between crashes and traffic flow.

Description of the summation variable Σ is eliminated to increase variable description conciseness.

The expectation was that $r_c = r_t$, which means $\pi = r_t\kappa = r_c\kappa$. Although it is an approximation, the ratio r_c should hold true for most datasets (Hauer, 1997). The time intervals (before and after) for the treatment group and comparison group must be the same for this relationship to be effective, otherwise both groups could be split into subsamples by comparing observations made during the same time periods before and after in both groups. If the link between crash risk and flow is the same for both groups and time periods, the adjustment for changes in traffic flow may not be necessary because it is indirectly recorded by the comparison group.

3.4 Benefit-Cost Analysis

Benefit-cost analysis offers a systematic method for assessing the advantages and disadvantages of a project (e.g., the installation of roundabouts) to determine if the project is economically beneficial. Benefit-cost analysis primarily entails the calculation and comparison of the entire cost and total benefit of the project over a specific period.

3.4.1 Identification of Costs

Construction costs are expenses directly connected to building the roundabout. They include expenses for labor, equipment, and materials. In comparison, maintenance costs, or charges, are expenses related to maintaining the roundabout after it has been put into use. Societal costs entail the price of traffic delays that occur during construction. Based on available data for this project, only construction costs were considered for analysis.

3.4.2 Identification of Benefits

Safety benefits result from reduced crash frequency and severity, while cost savings can be determined based on the average cost per crash from local or national crash data. Operational benefits such as shortened travel distances, reduced vehicle operating expenses, and decreased emissions are expected if the roundabouts increase traffic flow. Societal benefits of roundabouts, as identified by benefit-cost analysis, include improved appearance of the neighborhood and reduced noise levels, which may help increase property prices. This study considered only the safety benefits of roundabouts due to data availability. **Table 3.4** lists the Kansas crash costs used for the analysis, which were provided by KDOT. PDO crashes were not considered for cost calculation for this study since most go unreported, thereby increasing the unreliability of PDO crash data.

Table 3.4: Crash Costs

Crash Severity Level	Comprehensive Unit Cost (per crash), in 2024 USD
K	$ 13,999,597
A	$ 748,852
B	$ 240,505
C	$ 133,671
O	$ 11,691

The older crash (1994 to 1999 crash data provided by the KSHS) costs that were available were in the FIN scale. Due to the unavailability of crash data in the KABCO scale, the injury crash data categories A, B, and C were aggregated to derive a single cost value for all injury crashes. Using the recent dataset (2012–2022), the proportions of A, B, and C crashes among injury crashes were determined to be 6.42%, 38.41%, and 55.17%, respectively. These proportions were utilized to calculate a unified cost for the I (injury) category, resulting in a cost formula of $748,852 * 0.0642 + $240,505 * 0.3841 + $133,671 * 0.5517, which equals $214,173.25. The revised crash costs are presented in **Table 3.5**. In this method, it is assumed that the older injury crashes will have a similar distribution of A, B, and C severity levels due to the lack of KABCO scale data in older records.

Table 3.5: Revised Crash Costs

Crash Severity Level	Comprehensive Unit Cost (per crash), in 2024 USD
Fatal	$ 13,999,597
Injury	$ 214,173.25
PDO	$ 240,505

3.4.3 Calculation of Net Present Value

The economic viability of roundabouts can be evaluated by comparing the total cost and total benefits. When expenses and benefits are spread out over several years, the time value of money must be accounted for by discounting the benefits and costs to a common year, 2024 in this case. Costs in **Table 3.4** and every other cost for this study were adjusted for inflation using the Consumer Price Index (CPI) inflation calculator by the Bureau of Labor Statistics. The CPI tracks price variations in the United States and calculates the variations as a weighted average of goods and services that reflect the overall spending patterns of American consumers.

Chapter 4: Analysis and Results

The primary goal of this research was to evaluate the safety performance of rural roundabouts in Kansas. The analysis used before-and-after study methodology with comparison groups as outlined in Lord et al. (2021). This chapter details the data analysis and findings.

4.1 Analysis of Isolated Rural Roundabouts

Following the methodological approach suggested by Lord et al. (2021), this study collected and analyzed crash data for a period of three years before and after the opening of rural roundabouts. Comparison groups were also established to control confounding factors such as changes in traffic volume, overall crash trends, and weather conditions. **Figure 4.1** shows the locations of comparison sites selected for isolated rural roundabouts throughout Kansas. Site details are included in **Appendix A**.

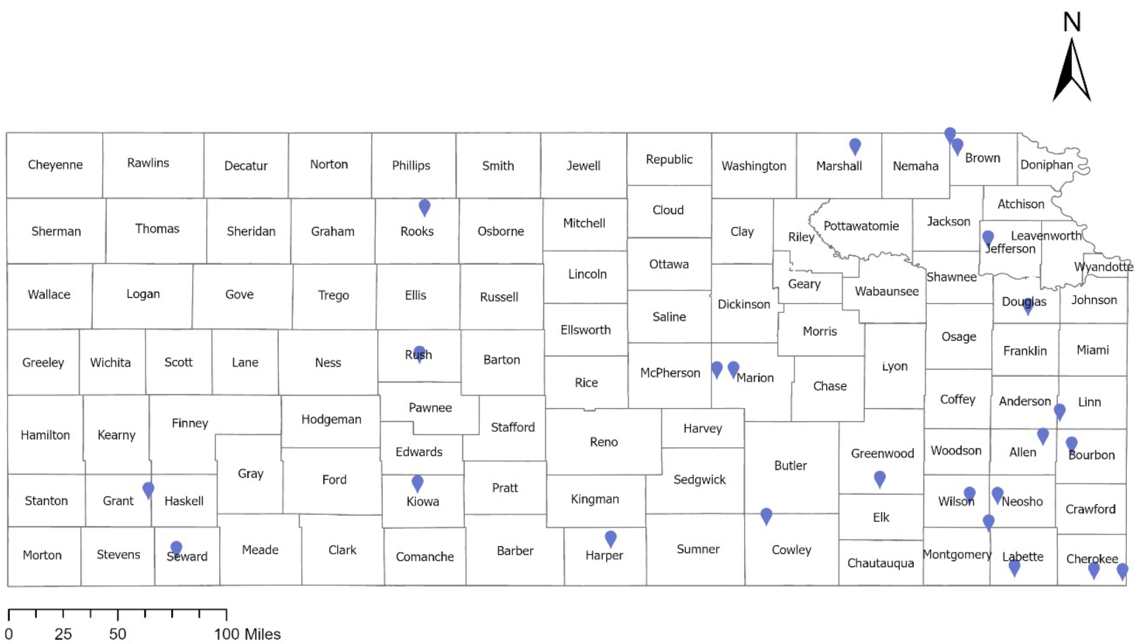

Figure 4.1: Locations of Comparison Sites for Rural Roundabouts

4.1.1 Descriptive Analysis

Traffic AADT was the primary focus when selecting comparison sites for this study. KDOT traffic count maps were used to select intersections based on total incoming AADT for one direction to compare intersections and roundabouts with similar AADTs (KDOT, 2023, June). Crash counts were collected for a total of six years for both the treatment and control groups, three years before and three years after the roundabouts were opened. For example, the roundabout on US-50 & US-77 from Marion County was opened in the year 2006, so crash count data for both this site and two comparison sites were collected from 2003 through 2005 and 2007 through 2009. **Table 4.1** shows the statistical comparison of treatment sites (rural roundabouts) and control sites (comparison intersection groups). As shown, the volume data were comparatively similar for the sites.

Table 4.1: Statistical Comparison of Rural Treatment and Control Sites

		Rural Roundabouts	**Rural Comparison Sites**
Number of Sites	-	12	24
Years of Data	Before	3	3
	After	3	3
Range of AADT	Before	879 to 8893	547 to 9782
	After	1481 to 9065	781 to 9737
Mean AADT	Before	5107	4730
	After	5055	4886
Variance of AADT	Before	3930228.243	3979373.694
	After	3920572.969	4736139.892
Standard Deviation of AADT	Before	1982.480326	1994.836759
	After	1980.043679	2176.267422
Total Fatal Crashes	Before	8	10
	After	3	9
Total Injury Crashes	Before	56	46
	After	26	43

The results showed that, although the number of fatal and injury crashes generally remained unchanged for the comparison groups (10 to 9 and 46 to 43, respectively), roundabouts significantly reduced both the fatal and injury crashes (8 to 3 and 56 to 26, 62.5% and 53.57% reductions, respectively). The detailed crash and volume counts are listed in **Appendix A**.

For preliminary analysis, the crash counts were normalized using the AADT, the AADTs were converted to vehicles per year, and then the fatal and injury crash counts were divided by the volume to obtain the crash rate (crash/million vehicles). **Figure 4.2** shows the normalized crash rates for the treatment (roundabouts) and control (comparison intersections) sites and the fatal and injury crash rates for before and after periods. As shown in the figure, the before crash rates for the injury and fatal crashes were higher for most treatment sites, while no significant difference was observed for the control sites.

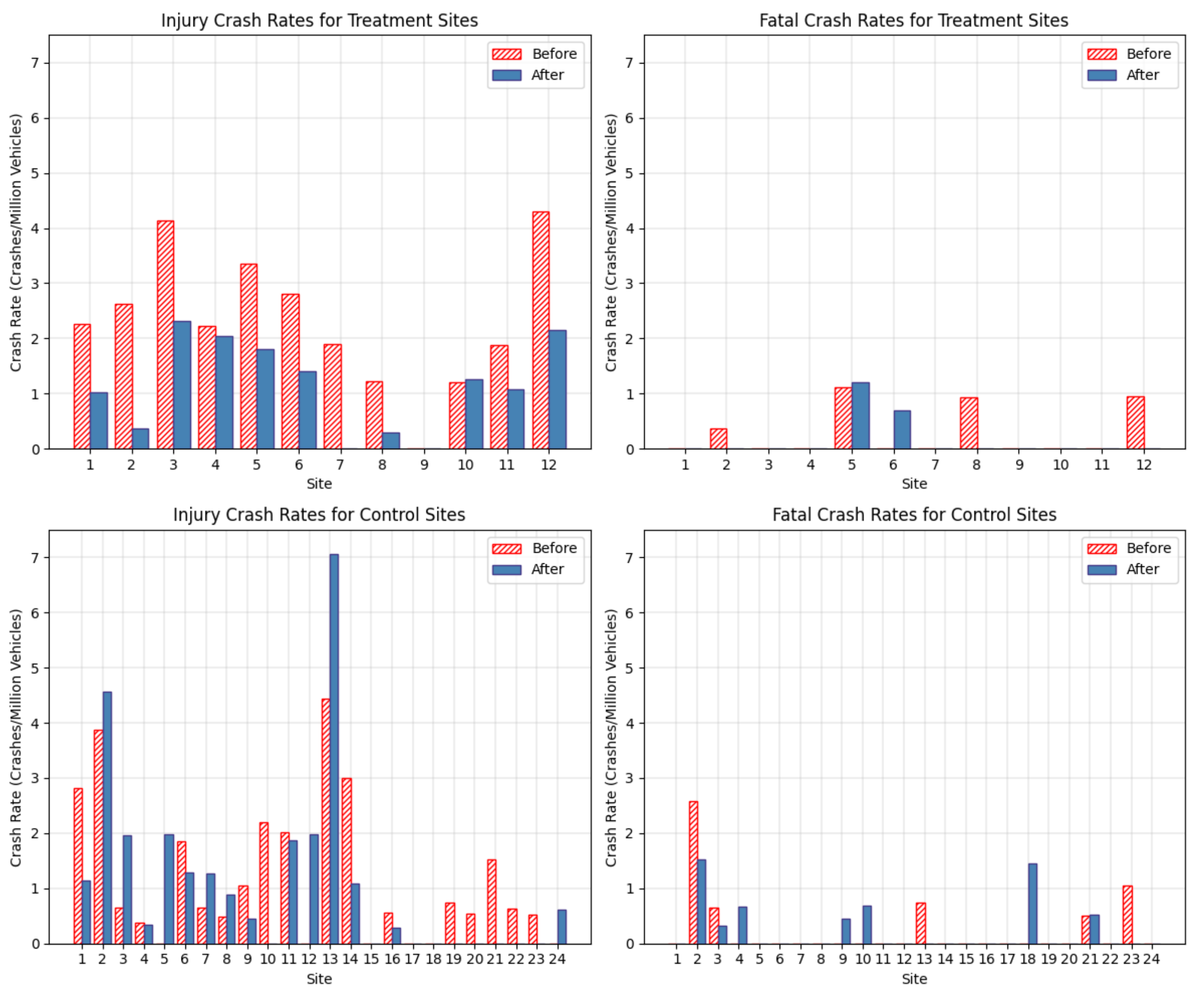

Figure 4.2: Crash Rate Comparison for Treatment and Control Sites for Rural Roundabouts

4.1.2 Statistical Analysis

The statistical analysis for crash counts utilized a simple before-and-after study and a before-and-after study using comparison groups. Using procedures in Lord et al. (2021), the crash reduction values of δ and θ were calculated with their respective significance levels, where δ is the reduction in the expected number of target crashes, and θ is the index or ratio between the estimated and expected number of target crashes. **Table 4.2** provides before-and-after analysis details of rural roundabouts.

Table 4.2: Before-and-After Analysis of Rural Roundabouts

Variable	Injury Crash	Fatal Crash	Fatal + Injury Crash
δ	30	5	35
Variance (δ)	82	11	93
Standard deviation (δ)	9.0554	3.3166	9.6436
θ	0.4561	0.3333	0.4462
p-value	< 0.05	> 0.10	< 0.05
Comment	The reduction is $30 \pm 1.96 * 9.0554$, significant at the 5% level	The reduction is $5 \pm 1.645 * 3.3166$, not significant at the 5% or 10% level	The reduction is $35 \pm 1.96 * 9.6436$, significant at the 5% level

The statistical analysis results in **Table 4.2** show a reduction of 30 in the expected number of injury crashes for all isolated rural roundabouts over the study period, and the value θ suggests a reduction of 45.61% in the expected number of injury crashes. The results also reveal that the reduction in injury crashes was significant at the alpha level of 0.05, with 33.33% and 44.62% reductions in fatal and fatal plus injury crashes, respectively. Although the reduction in fatal crashes was not significant at the 0.05 level of significance, the total number of injury and fatal crashes significantly decreased at the 0.05 level of significance, meaning that, with 95% confidence, a reduction in the number of fatal and injury crashes with the installation of rural roundabouts.

The comparison groups were then considered, with results tabulated in **Table 4.3**, which indicates a reduction of 26.3 in the expected number of injury crashes. In addition, the value θ suggests a reduction of 46.69% in the expected number of injury crashes. The results also show that the reduction in injury crashes was significant at the alpha level of 0.07, meaning the significance level increased with the introduction of comparison sites. A 31.16% reduction of fatal crashes was observed, while a reduction of 46.34% occurred for fatal plus injury crashes. Although the reduction in fatal crashes was not significant, the total number of injury and fatal crashes combined decreased significantly at the 0.06 level, meaning that, with 94% confidence, the number of fatal plus injury crashes decreased with the installation of rural roundabouts.

Table 4.3: Before-and-After Analysis of Rural Roundabouts with Comparison Groups

Variable	Injury Crash	Fatal Crash	Fatal + Injury Crash
δ	26.3	4.2	30.4
Variance (δ)	200.9735	20.4758	245.4674
Standard deviation (δ)	14.1765	4.5250	15.6674
θ	0.4669	0.3116	0.4634
p-value	< 0.07	> 0.10	< 0.06
Comment	The reduction is $26.3 \pm 1.81 * 14.1765$, significant at the 7% level	The reduction is $4.2 \pm 1.645 * 4.5250$, not significant at the 5% or 10% level	The reduction is $30.4 \pm 1.88 * 15.6674$, significant at the 6% level

4.1.3 Benefit-Cost Analysis

Installation costs for the isolated rural roundabouts (not including rural interchange roundabouts) were collected from the KDOT database to perform the benefit-cost analysis. All costs were adjusted for inflation and converted to present value as of May 2024. The 2024 value for the isolated rural roundabout installations, or total cost, was $45,669,373.21, as detailed in **Table 4.4.**

Table 4.4: Cost Calculation of Isolated Rural Roundabouts

Roundabouts	Year Opened	KDOT/City Proj. No.	Installation Cost	2024 Value
N. Jct. of US-59 & US-169	2006	K-9243-01	$2,199,453	$3,464,243.84
US400/US-69 Alternate/K-66/Beasley	2008	KA-0483-01	$1,862,499	$2,755,912.63
East Jct. US-77 & US-166	2009	KA-1147-01	$1,513,798	$2,239,276.49
US-59/US-160	2020	KA-4536-01	$3,053,813	$3,697,328.47
US-50 & US-77	2006	K-7417-02	$2,917,389	$4,595,027.44
US-56/US-77/K-150	2015	KA-2770-02	$5,405,477	$7,224,017.43
K-68 & Old Kansas City Rd/Hedge Lane	2001	K-6001-01	$1,497,471	$2,671,091.45
US-75/K-31/K-268	2011	KA-0047-01	$2,620,432	$3,716,436.37
K-18 and Karns	2020	KA-5132-01	$2,131,773	$2,580,991.37
US-50/K-281	2020	KA-4514-01	$5,695,405	$6,895,570.57
East Jct. US-81 & US-160 (15th/16th/A Street)	2011	KA-0844-01	$1,146,102	$1,625,462.96
US-400 and K-47	2009	KA-0484-01	$2,842,002	$4,204,014.19
			Total cost=	**$45,669,373.21**

Safety benefits over a period of 20 years were calculated for benefit analysis. The fatal and injury crash savings for three years were found from the before-and-after analysis (5 and 30 crashes, respectively). Crash costs from **Table 3.5** (converted to 2024 dollars) (U.S. Bureau of Labor Statistics, n.d.) were multiplied by the number of crashes and then divided by 3 to find the per-year benefit. Benefits for 20 years were then calculated, totaling $509,487,883.63, resulting in a benefit-cost of 11.16:1. Details of this benefit calculation are shown in **Table 4.5.**

Results of the before-and-after analysis with comparison groups for the estimated fatal and injury crash reduction for three years was 4.2 and 26.3 crashes, respectively. Crash costs from **Table 3.5** (converted to 2024 dollars) were multiplied by the number of crashes and then divided by 3 to find the per-year benefit, from which the total benefits for 20 years were calculated as $429,540,426.09, resulting in a benefit-cost ratio of 9.41:1.

Table 4.5: Benefit Calculation of Isolated Rural Roundabouts

	Simple Before-and-After		With Comparison Groups	
	Fatal	**Injury**	**Fatal**	**Injury**
Crash Cost	$13,999,597.00	$214,173.25	$13,999,597.00	$214,173.25
Crashes saved in 3 yr	5	30	4.2	26.3
Benefit/Year	$23,332,661.67	$2,141,732.51	$19,599,435.80	$1,877,585.50
Benefit for 20 yr	$466,653,233.33	$ 42,834,650.30	$391,988,716.00	$ 37,551,710.09
Total Benefit		$509,487,883.63		$429,540,426.09
Total Cost		**$45,669,373.21**		**$45,669,373.21**
B/C Ratio		**11.16:1**		**9.41:1**

4.2 Analysis of Rural Interchange Roundabouts

In this research, rural interchange roundabouts (**Table 3.2**) were subjected to separate analysis from isolated rural roundabouts due to their distinct characteristics, the unavailability of comparable sites, and variations in the number and types of crashes. This study conducted a before-and-after analysis without comparison sites that focused exclusively on injury crashes. This part of analysis did not include any comparison sites.

4.2.1 Descriptive Analysis

The processes of collecting and sorting data for the rural interchange roundabouts were similar to the processes for the isolated rural roundabouts. For each site, three years of data before and three years after the opening of roundabouts were collected. Of the 16 sites, 12 were converted to roundabouts from another type of interchange, so before-and-after analysis was performed on those 12 sites. The list of 16 roundabouts is provided in Appendix A.

Following a similar methodology used for isolated rural roundabouts, crash statistics were adjusted based on the AADT, with AADTs recalculated into vehicles per year to normalize the crash data across different periods and enhance the accuracy. Subsequently, the number of injury crashes was normalized by traffic volume to determine the crash rate (crash/million vehicles). **Figure 4.3** illustrates the adjusted crash rates for rural interchange roundabouts, comparing injury crash rates for the periods before and after the implementation of roundabouts. The data presented in the figure indicates that the injury crash rates were generally higher in the before period compared to the after period for most sites.

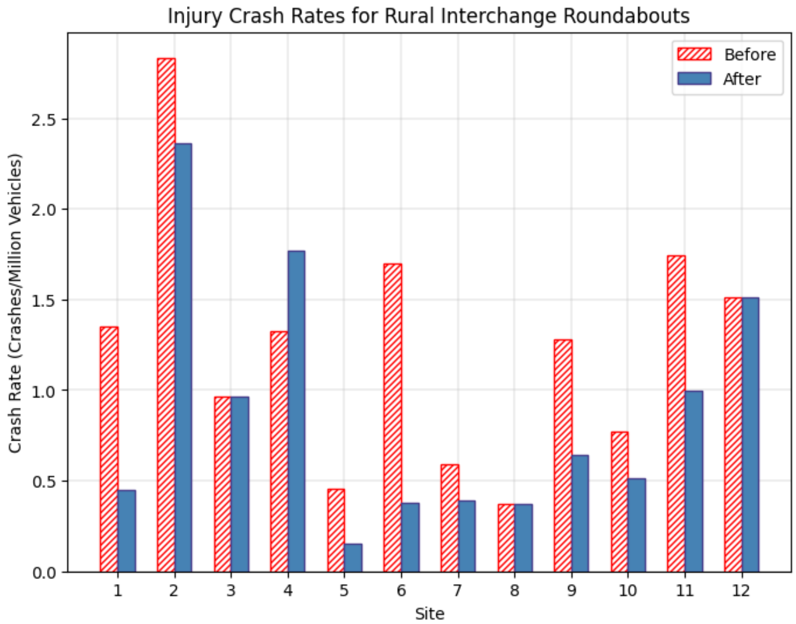

Figure 4.3: Crash Rate Comparison for Rural Interchange Roundabouts

4.2.2 Statistical Analysis

As mentioned, a simple before-and-after study was conducted on these sites according to procedures in Lord et al. (2021). The crash reduction values of δ and θ were calculated with their respective significance levels, where δ was the reduction in the expected number of target crashes, and θ was the index or ratio between the estimated and expected number of target crashes. **Table 4.6** provides analysis details for the rural interchange roundabouts.

Table 4.6: Before-and-After Analysis of Rural Interchange Roundabouts

Variable	Injury Crash
δ	18
Variance (δ)	100
Standard deviation (δ)	10
θ	0.6833
p-value	< 0.08
Comment	The reduction is $18 \pm 1.75 * 10$ significant at the 8% level

The statistical analysis results in **Table 4.6** show a reduction of 18 in the expected number of injury crashes for all the rural interchange roundabouts over the study period. In addition, the value θ suggests a reduction of 68.33% in the expected number of injury crashes, which was not significant at the 0.05 level of significance but was significant at the 0.08 level of significance. Therefore, with 92% confidence, a reduction occurred in the number of injury crashes with the installation of roundabouts.

4.2.3 Benefit-Cost Analysis

Although the construction costs of rural interchange roundabouts were accessible, a benefit-cost analysis was not conducted due to insufficient data on fatal crashes (zero fatal crashes in the before period and one fatal crash in the after period), meaning a benefit-cost analysis with these data could lead to skewed or misleading conclusions. Sole reliance on the cost of injury crashes would not provide a comprehensive parameter for inclusion in the benefit-cost analysis.

4.3 Results

The before-and-after analysis revealed a reduction of 30 and 5 in the expected number of injury and fatal crashes, respectively, for all the isolated rural roundabouts over the 6 years before-after study period. In addition, a reduction of 45.61% occurred in the expected number of injury crashes, which was significant at the alpha level of 0.05. Results showed a 33.33% and 44.62% reduction of fatal and fatal plus injury crashes, respectively, and the total number of injury and fatal crashes had a significant reduction at the 0.05 level, meaning that, with 95% confidence, there was a reduction in the number of fatal plus injury crashes with the installation of the rural roundabouts.

After introducing comparison groups, the reduction in the expected number of injury and fatal crashes was 26.3 and 4.2, respectively, as well as a reduction of 46.69% in the expected number of injury crashes. The reduction in injury crashes was significant at the alpha level of 0.07. In addition, a 31.16% and 46.34% reduction of fatal and fatal plus injury crashes were observed. Although the reduction in fatal crashes was not significant, the total number of injury and fatal crashes combined demonstrated a significant reduction at the 0.06 level, meaning that, with 94%

confidence, there was a reduction in the number of fatal plus injury crashes combined with the installation of the rural roundabouts.

A benefit-cost analysis was performed using the reduced number of crashes for both methods. Using data from the before-and-after study, the total benefit was found to be $509,487,883.63 over 20 years and $429,540,426.09 using comparison groups. The benefit-cost ratio was 11.16:1 and 9.41:1, respectively.

For rural interchange roundabouts, the analysis indicated an 18-crash reduction in expected injury crashes throughout the study, with a 68.33% decrease in expected injury crashes. Despite not achieving significance at the 0.05 level, the reduction was significant at the 0.08 level, allowing for 92% confidence in the injury crash reduction linked to roundabout installations.

4.4 Comparison with Other Studies

The results of this study are consistent with the literature on roundabout safety performance. For example, Retting et al. (2001) observed substantial decreases in crash rates, with a 38% reduction for all levels of crash severity, a 76% reduction in injury-related crashes, and a 90% reduction in the number of fatal and serious injury crashes. Persaud et al. (2001) estimated a 39% reduction in crashes of all severities, a 76% reduction in injury crashes, and reductions in fatal and severe injury crashes of approximately 90%. Although the effectiveness of roundabouts may vary based on design, road characteristics, and traffic behavior, the results of this study and the literature affirm the role of roundabouts in enhancing road safety (Gross et al., 2013).

Chapter 5: Conclusions and Recommendations

5.1 Conclusions

This research effort affirmed the safety advantages of rural roundabouts by demonstrating their success at considerably lowering both injury and fatal crashes. This trend was supported by before-and-after analysis and comparison group analysis performed for isolated rural roundabouts, which both showed statistically significant decreases in the total number of fatal plus injury crashes (35 and 30.4) and the number of injury crashes (30 and 26.3). Favorable benefit-cost ratios of 11.16:1 and 9.41:1 were also shown for isolated rural roundabouts using both methods, which highlight the cost-effectiveness of isolated rural roundabouts, demonstrate a significant return on investment, and support their continued use. The analysis for rural interchange roundabouts showed a decrease of 18 expected injury crashes over the study period and a 68.33% reduction in expected injury crashes, which both contribute to enhanced road safety.

Maintenance costs for roundabouts were not included in this analysis. Recognizing these costs could slightly increase the expense components of the benefit-cost ratios, but given the robust ratios observed, their inclusion is unlikely to significantly alter the overall conclusions. Future studies could beneficially investigate this aspect.

5.2 Recommendations

Given their proven ability to significantly reduce both injury and fatal crashes, rural roundabouts should continue to be constructed in Kansas. To extend these conclusions and advocate the use of roundabouts as a safer alternative to conventional intersections, similar research should be conducted in other rural communities throughout the United States. Given the favorable benefit-cost ratio, stakeholders and policymakers should prioritize rural roundabouts as a crucial component of traffic safety plans, and future long-term studies should assess the ongoing effectiveness of roundabouts and their changing performance over time. In conclusion, this study provides robust evidence to support the safety benefits of rural roundabouts. The potential for these interventions to significantly reduce fatal and injury crashes, coupled with a favorable benefit-cost ratio, supports their continued implementation.

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Appendix A: Detailed Data for Analysis

Table A.1: Volume and Crash Count Data of Isolated Rural Roundabouts

Sl no.	Intersection	County	AADT		Crash Counts			
			Before	After	Before		After	
					Fatal	Injury	Fatal	Injury
1	N. Jct. of US-59 & US-169	Anderson	4848	5317	0	4	0	2
2	US-400/US-69 Alternate/K-66/Beasley	Cherokee	7310	7607	1	7	0	1
3	East Jct. US-77 & US-166	Cowley	6617	7122	0	10	0	6
4	US-59/US-160	Labette	4937	4028	0	4	0	3
5	US-50 & US-77	Marion	4902	4570	2	6	2	3
6	US-56/US-77/K-150	Marion	3905	3910	0	4	1	2
7	K-68 & Old Kansas City Rd/Hedge Lane	Miami	2885	2990	0	2	0	0
8	US-75/K-31/K-268	Osage	8893	9065	3	4	0	1
9	K-18 and Karns	Riley	879	1481	0	0	0	0
10	US-50/K-281	Stafford	4516	4368	0	2	0	2
11	East Jct. US-81 & US-160 (15th/16th/A Streets)	Sumner	5858	5115	0	4	0	2
12	US-400 and K-47	Wilson	5728	5083	2	9	0	4

Table A.2: Volume and Crash Count Data of Rural Interchange Roundabouts

Sl no.	Intersection	County	AADT		Crash Counts			
			Before	After	Before		After	
					Fatal	Injury	Fatal	Injury
1	I-70 WB Ramps & US-40B (Washington St.)	Geary	6077	6077	0	3	0	1
2	I-70 WB Ramps & Chestnut/East Streets	Geary	5800	5800	0	6	0	5
3	I-135 & Broadway (new interchange)	Harvey	8550	8550	0	3	0	3
4	I-135 & 1st Street (new interchange)	Harvey	12400	12400	0	6	0	8
5	US-50 & Anderson (Interchange)	Harvey	18000	18000	0	3	0	1
6	K-7 & Johnson Dr/55th Street (Interchange)	Johnson	14500	14500	0	9	0	2
7	I-35 & US-50 Connector (Interchange)	Lyon	13975	13975	0	3	0	2
8	US-50 Connector & US-50 (Interchange)	Lyon	14700	14700	0	2	0	2
9	K-18 and Scenic Drive	Riley	12825	12825	0	6	0	3
10	I-70 EB & Rice Rd/Cyprus Drive	Shawnee	10650	10650	0	3	0	2
11	I-70 WB & Rice Rd./Sycamore Drive	Shawnee	11000	11000	0	7	1	4
12	US-75 & 46th Street	Shawnee	14500	14500	0	8	0	8

Table A.3: List of Comparison Sites for Rural Roundabouts

No.	Intersection	County	Latitude	Longitude
1	W. Jct. of US-400 & K-99	Greenwood	37.63633	-96.253417
2	US-54 & US-59/Cedar St	Allen	37.92161	-95.17
3	US-400 & US-169	Montgomery	37.3468	-95.530648
4	US-75 & US-36	Brown	39.84149	-95.737566
5	E. Jct. of US-56 & K-15	Marion	38.36234	-97.334981
6	US-166/US-400 & K-26/ SE Bagdad rd	Cherokee	37.02363	-94.642312
7	US-75 & K-246/280th st	Brown	39.91425	-95.786312
8	K-4 & K-92/102nd st	Jefferson	39.23077	-95.534857
9	US-169 & K-47	Neosho	37.52884	-95.471543
10	K-99 & US-36/Pony Express Hwy	Marshall	39.84161	-96.41704
11	US-75 & K-47	Wilson	37.52992	-95.656775
12	US-183 & US-24	Rooks	39.43666	-99.275122
13	US-166 & K-101	Labette	37.04837	-95.35924
14	US-54 & K-3	Bourbon	37.86347	-94.979392
15	US-400 & US-183	Kiowa	37.60607	-99.321989
16	US-56 & US-59	Douglas	38.7824	-95.269004
17	K-31 & K-3/Arthur rd	Linn	38.08124	-95.059008
18	US-160/E Oklahoma Ave & K-190/ S Rd X	Grant	37.56197	-101.10848
19	US-183/S Main st & K-96/Union st	Rush	38.46576	-99.30883
20	US-166 & US-69	Cherokee	37.03126	-94.831479
21	US-77 & K-15/62nd rd	Cowley	37.3897	-97.006258
22	W Jct. of US-56 & K-15	Marion	38.36288	-97.224572
23	US-83 & K-51	Seward	37.17022	-100.92293
24	US-160 & K-2/NE 70 ave	Harper	37.23933	-98.039373

Table A.4: List of Installation Years for Each Isolated Rural Roundabouts

Sl no.	Intersection	City	County	Legs	Lanes (each side)	Year Opened	KDOT/City Proj. No.
1	N. Jct. of US-59 & US-169	Garnett	Anderson	3	1	2006	K-9243-01
2	US400/US-69 Alternate/ K-66/Beasley	Riverton	Cherokee	4	1	2008	KA-0483-01
3	East Jct. US-77 & US-166	Arkansas City	Cowley	4	1	2009	KA-1147-01
4	US-59/US-160	Altamont	Labette	4	1	2020	KA-4536-01
5	US-50 & US-77	Florence	Marion	5	1	2006	K-7417-02
6	US-56/US-77/K-150		Marion	4	1	2015	KA-2770-02
7	K-68 & Old Kansas City Rd/Hedge Lane	Paola	Miami	5	1	2001	K-6001-01
8	US-75/K-31/K-268		Osage	4	1	2011	KA-0047-01
9	K-18 and Karns	Junction City	Riley	4	1	2020	KA-5132-01
10	US-50/K-281		Stafford	4	1	2020	KA-4514-01
11	East Jct. US-81 & US-160 (15th/16th/A Streets)	Wellington	Sumner	4	1	2011	KA-0844-01
12	US-400 and K-47	Fredonia	Wilson	4	1	2009	KA-0484-01

Table A.5: List of Installation Years for Each Rural Interchange Roundabouts

Sl no.	Intersection	City	County	Legs	Lanes (each side)	Year Opened	KDOT/City Proj. No.
1	I-70 & Exit 202*	Lawrence	Douglas	3	1	2008	-
2	I-70 & Exit 204*	Lawrence	Douglas	3	1	2010	-
3	I-70 WB Ramps & US-40B (Washington St.)	Junction City	Geary	5	1	2006	K-9034-01
4	I-70 WB Ramps & Chestnut/East Streets	Junction City	Geary	5	1	2009	K-8255-01
5	I-135 & Broadway (new interchange)	Newton	Harvey	6	1	2003	K-5634-01
6	I-135 & 1st Street (new interchange)	Newton	Harvey	6	1	2003	K-5634-01
7	US-50 & Anderson (Interchange)	Newton	Harvey	6	1	2014	K-9439-01
8	K-7 & Johnson Dr/55th Street (Interchange)	Shawnee	Johnson	6	2	2011	K-7925-02
9	I-35 & US-50 Connector (Interchange)	Emporia	Lyon	3	1	2008	K-9924-01
10	US-50 Connector & US-50 (Interchange)	Emporia	Lyon	3	1	2008	K-9924-01
11	K-18 and Scenic Drive		Riley	5	2	2012	KA-0410-01
12	I-70 EB & Rice Rd/Cyprus Drive	Topeka	Shawnee	4	1	1999	K-6252-01
13	I-70 WB & Rice Rd./Sycamore Drive	Topeka	Shawnee	4	1	1999	K-6252-01
14	US-75 & 46th Street	Topeka	Shawnee	4	2	2003	K-6680-01
15	KTA roundabout to casino NB I-35*	Mulvane	Sumner	4	1	2011	-
16	KTA roundabout to casino SB I-35*	Mulvane	Sumner	3	1	2011	-

** These roundabouts, which were newly constructed at sites without previous traditional intersections, were excluded from further analysis due to the lack of pre-installation data*

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