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# Impact of Road Median Characteristics on Safety Performance: A Review Study

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## Abstract

Roadway crashes remain a major global concern, accounting for nearly one-third of all traffic-related fatalities, particularly in mountainous regions. This study reviews and analyzes the impact of road median barrier characteristics on traffic safety, focusing on their role in minimizing crash frequency and severity. A systematic literature review was conducted to evaluate different median barrier types, materials, and configurations. Additionally, a case study was carried out to assess the effectiveness of cable median barriers in improving safety performance. Key findings from the literature review include that raised medians reduce overall crash frequency by 39%. The case study revealed that cable median barriers demonstrated high effectiveness, preventing over 90% of vehicles from crossing the median in the event of a collision. The review identifies a significant correlation between median design and crash outcomes, indicating that raised medians can reduce crash frequency by approximately 39%. The case study findings show that cable median barriers prevented over 90% of vehicles from crossing the median during collisions. The novelty of this work lies in its combined assessment of both literature and field data to provide a comprehensive understanding of median barrier efficiency and to highlight practical design implications for safer roadway systems.

**Keywords:** Median Barriers; Traffic safety; Operational Safety; Crash severity.

## 1 Introduction

Roadside crashes account for roughly one-third of all injuries and deaths each year [1]. The geometric design of roads is critical for road safety [2]. Crashes and crashes involving fixed roadside objects, such as safety barriers, bridge supports, drainage devices, mailboxes, poles, and trees, are expected to cost more than $3 billion per year [3]. Safe road design contributes to a long-term decrease in the number of crashes and the seriousness of such crashes [4]. One of the design features that can enhance road safety is the design of road cross-sections, including shoulder width, lane width, and median form selection [5]. The most significant reason for having medians is to separate traffic [6]. There is a variety of research on the safety efficiency of medians, as there is for other roadside objects [7]. Median barriers protect against hazards such as immovable obstacles, non-traversable cliffs, and opposing traffic [8].

The road median is the space between the two lanes of traffic that divides traffic flowing in opposite directions. Some of the road medians' purposes include: preventing crashes, providing a crossing area for pedestrians and cyclists, and setting up the lighting system. Medians can be used for installing traffic signs and signals to reduce headlight glare from oncoming traffic, and in some rural areas, they may assist as emergency parking spaces.

Despite improved through-traffic flow and higher traffic density per median opening, the Florida Department of Transportation (FDOT) conducted research in 1995. It showed that overall decreases in the number of median openings along the transportation system were consequent in crash rate drops [9]. Perception/reaction distance, turn radius, queue storage, and deceleration length should all be considered when evaluating the spacing of median openings, according to the FDOT Median Handbook (1997) [10]. Zhou et al. 2002 [11] revealed that under some traffic conditions, full median openings may not be as successful as directional and left-in-only median openings in terms of traffic flow. The construction of a directional median opening on multilane highways has caused a rise in U-turning vehicles at downstream unsignalized intersections [12]. The presence of a median on the main road shows a statistically significant positive effect on safety, specifically at unsignalized intersections [13]. This finding aligns with research focused on three-legged intersections [14], particularly those controlled by stop signs [15]. This suggests that medians may contribute to safety by guiding and organizing the flow of traffic.

The safety effects of median modifications, such as full median openings to lateral median openings or full median openings to left-in-only median openings, have been estimated in several studies [16-20]. Xu 2001 [21] compared the crash rates of directional/left-in only openings with complete median openings using a cross-sectional before-and-after analysis form. Pirinccioglu et al. 2006 [22] addressed the conflict rates of directional/left-in only median openings with complete median openings in a traffic conflict analysis to assess the safety efficiency of various median openings. According to Stine et al. 2010 [23], fitting a longitudinal median barrier will reduce the severity of median-related crashes.

Although many previous studies have explored the role of medians and barriers in improving road safety, most have focused on isolated aspects such as crash frequency, geometric design, or barrier type without a comprehensive analysis that connects these elements to overall safety performance. Moreover, there remains a limited understanding of how different median characteristics collectively influence crash occurrence and severity under varying road and traffic conditions. To address this gap, the present study aims to investigate the safety performance of road medians by examining crash distribution patterns, the effectiveness of barriers in preventing and reducing crash severity, and the comparative performance of different barrier types. The novelty of this work lies in integrating findings from diverse crash datasets and literature to establish a clearer relationship between median design features and safety outcomes. The results of this study are expected to provide valuable insights for transportation agencies and engineers to optimize median design, enhance road safety, and support data-driven decision-making in roadway planning and management.

## 2 Methods and Materials

### 2. 1 Median Characteristics

A median's features comprise providing a protected space for out-of-control cars, separating opposing traffic, providing emergency stopping areas, providing storage areas for left- and U-turning vehicles, providing pedestrian shelter, and reducing headlight glare [24].

A median's width is the gap between the inside lanes' sides, together with the median shoulders. In general, median widths range from 1.2 m, usually in urban areas, to 24 m or more in rural areas [25]. Median widths should be as large as possible, but they must be balanced against other cross-section elements and the cost involved. The broader the median, overall, the better it is at providing secure working circumstances and a safe area for out-of-control vehicles.

Hadi et al. 1995 [26] utilized negative binomial models to demonstrate that median width has an effect on multilane highways, and the investigators created 2 models depending on the number of lanes and the traffic volume range. Their findings indicated that an increase in median width was associated with a decrease in the number of crashes. According to Hauer 2000 [27], it was not possible to classify Crash Modification Factors (AMFs) for median width, but three safety patterns were noted instead: Wider medians minimize cross-median crashes (i.e., collisions between opposing vehicles); The number of median-related crashes rises as the median width rises, up to 30 feet, and then falling as the median becomes broader than 30 feet; however, the overall impact of median width on total crash rates remains a subject of debate. The creation of a collection of AMFs for the influence of median width on crashes for 4-lane rural roadways was identified in the interim report for NCHRP Project 17-27 [28], as shown in Table 1. Table 1 summarizes the suggested values, which have been updated from the report's usual baseline of 30-ft medians. The values of AMFs recommended by Stamatiadis 2009 [6] and provided in Table 2 are greater than those predicted in the Highway Safety Manual (HSM) [29]. The disparity may be attributed to the way the Highway Safety Manual (HSM) directly interprets median-related crashes. The medians of road segments with a barrier are usually narrower, which could affect the AMFs, as seen in the HSM values.

**Table 1:** AMFS for Rural Multilane Roadways' Median Width.

| **Barrier** | **Median width feet** | | | | | |
|---|---|---|---|---|---|---|
| | **15** | **20** | **30** | **40** | **50** | **60** |
| With | 1.000 | 0.997 | 0.990 | 0.984 | 0.977 | 0.971 |
| Without | 1.000 | 0.994 | 0.981 | 0.969 | 0.957 | 0.945 |

**Table 2:** AMFS Recommended for Divided Roadways with Median Width.

| Category | Median width feet | | | | | |
|---|---|---|---|---|---|---|
| | 10 | 20 | 30 | 40 | 50 | 60 |
| Multi-vehicle | 1.00 | 0.91 | 0.83 | 0.75 | 0.68 | 0.62 |

## 2. 2 Data Collection

The study was undertaken utilizing a diversity of databases, comprising Web of Science, SCOPUS, Google Scholar, and others, with the terms updated, median, median type, and median barriers as primary search keywords. To precisely mimic the current review, the most cited works and the most recent innovations in the field were included. The four basic types of medians are: Depressed, Closed, Raised, and Painted or Flush, including the following categories: Traversable (Flush) and Non-Traversable (Barrier and Deterring).

Traversable road medians are those that allow vehicles to move in the event of an emergency. The suggested traversable median width is 7 m, according to the NHA [30]. A traversable median does not physically prevent vehicles from crossing or entering it due to its construction [31]. This may include painted medians, see Figure 1. A traversable median is a noticeable separation without any physical barrier that can be crossed with comfort and ease, whether it is elevated, depressed, or flush [32,33].

Flush medians can be used to wait and slow down before turning right from the lane or to wait for a break in the traffic flow after turning right onto the road [34]. Right-turning bays, also known as 'right-turn pockets,' are often found inside flush medians [35]. They are not the same as a single right-turn bay. Marking these bays is typically for roadside areas having a high amount of traffic. Otherwise, the intersection would be marked with a flush median all the way around.

In the construction of rural highways that frequently assist high-speed traffic, a raised curb median has been used. Painted medians have become more common in recent years for road-widening projects. The proper width for painted medians is still up for debate, as is how painted medians affect driver stress and, as a result, driver performance [4]. On the Bruce Highway in Queensland, Australia, Whittaker 2012 [36] investigated the safety benefits of installing a 1 m wide continuous painted median strip with audio-tactile line-marking. The narrow painted median strip offers significant safety benefits by crash mitigation and is relatively inexpensive to install, see Figure 2. Furthermore, to investigate driver behavior on rural two-lane highways, Montella et al.'s driving simulator study [37] found that medians, as a type of visual marking, had a significant impact on driver behavior when approaching and driving through curves on rural two-lane highways. They pointed out that when drivers could detect the curve sooner due to this treatment, their deceleration on approach was significantly affected, giving them more time to slow down gradually. The effects of various treatments on driving behavior at the main approaches of a rural intersection were investigated by Montella et al. 2011 [38]. The results indicated that a raised median island was among the most effective treatments for influencing driving performance.

A non-traversable median is a physical barrier that separates opposing vehicular traffic on a street or driveway [39]. Physical barriers (such as a grass or swale median, a raised concrete curb and/or island, and a concrete fence) that prevent traffic from moving across the median are examples of non-traversable medians [40].

The barrier median is the part of the road where vehicles are not allowed to pass. Concrete or steel is used to construct it. The most popular use of median barriers is to distinguish opposing traffic paths on a separated highway [41,42]. Although these systems do not minimize the number of crashes caused by roadway exits, they may certainly help avoid a median crash from being a head-on collision with a median crossover [43]. The three basic types of median barriers are rigid barrier systems, semi-rigid barrier systems, and flexible barrier systems [44].

The most popular form of rigid median barrier in use today is concrete [45], see Figure 3. Despite their relatively high initial cost of construction, concrete barriers are known for their relatively low life-cycle cost, efficient safety presentation, and comparatively maintenance-free characteristics. One disadvantage is that crashes involving rigid barriers can result in more serious injuries, as a rigid barrier absorbs the least energy in a crash compared to other barrier schemes. Concrete barriers, on the other hand, have proven to be very effective at preventing median crossover collisions, particularly in high-traffic areas with high speeds. These barrier systems have proved to be highly active in areas of heavy traffic volumes and speeds. Concrete barrier systems are also very useful in areas where there is a lot of truck traffic or where there aren't enough median widths to accommodate other barrier arrangements.

Semi-rigid barriers, also known as guardrails or guiderails, are made up of interconnected metal railing sections braced by posts and blocks [46]. The semi-rigid barrier scheme is best used in traversable medians with little to no grade and cross-slope transition, see Figure 4. Semirigid barriers are less expensive than rigid barriers, but they are more difficult to build in sloped areas with poor soil conditions. In addition, the need for repairs after an effect will increase the life-cycle cost. Guardrail schemes are built to absorb energy in the event of a collision, and the whole assembly is designed to deflect or shift in the event of a collision.

A typical cable barrier is made up of several steel cables that are attached to a sequence of posts; see Figure 5. These barriers are thought to be the utmost adaptable and forgiving in terms of reducing the severity of median crossover collisions [47]. The forces on the vehicle and its inhabitants are reduced, and the majority of the energy from a collision is absorbed by cable median barriers. Cable barrier approaches are usually less expensive to build than rigid and semi-rigid barrier systems. However, similar to guardrails, they usually need maintenance after a crash and thus have a higher life cycle cost. The ease with which these barrier structures can be maintained and repaired is a significant factor. When some posts are struck in a single collision, the barrier structure can be vulnerable to future crossovers before the damaged segment is repaired. Some high-tension systems are designed to resist impact forces and minimize deflection. When posts are struck, these high-tension systems are easier to fix, and they have the supplementary benefit of being suitable for use in tighter spaces.

The term "deterring median" refers to an artificial median that can be discarded in the event of a sudden and unexpected event (emergency) that necessitates immediate action to prevent catastrophe [48,49], see Figure 6. For example, if a thief or criminal is apprehended, the median can be eliminated, allowing police to quickly apprehend the thief. The deterring median could be passable or impassable. Table 3 shows some review papers in the area of using different road median barriers on safety performance.


**Figure 1:** Traversable median

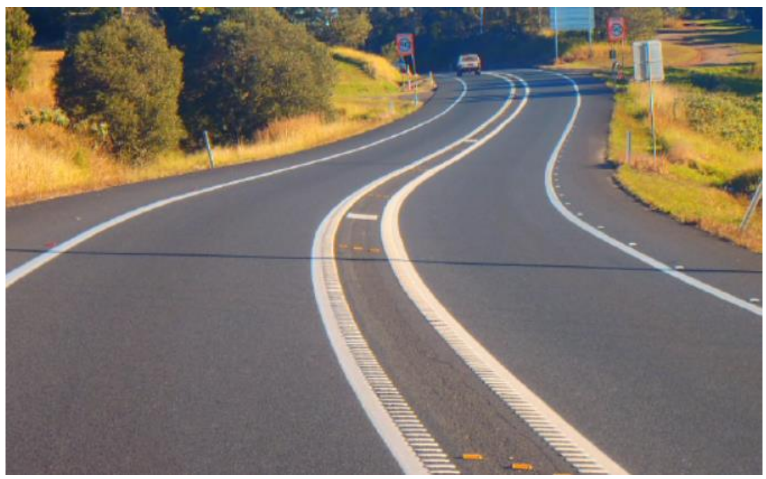

**Figure 2:** Continuous Painted Median Strip Installation [36]

**Figure 3:** Rigid barrier: Semi-Rigid Barriers

**Figure 4:** Rigid Barrier: Concrete Barrier

**Figure 5:** Rigid barrier: Deterring Barriers

**Figure 6:** Rigid barrier: Cable Barriers

**Table 3:** Safety Performance Outcomes Based on Literature Review.

| No. | Author | Median Type | Safety Performance Outcomes |
|---|---|---|---|
| 1 | Ray and McGinnis (1997) [50] | In-situ Concrete Barriers | This can result in a more severe crash, particularly when a small vehicle is involved. |
| 2 | Hunter et al. (2001) [51] | Three-strand cable median barriers | They came to the conclusion that overall crash frequencies increased after the median was installed, but only to the extent of freeways without cable barriers. |
| 3 | Martin et al. (2001) [52] | Steel and Concrete Barriers | In crashes with concrete walls, the proportion of crashes out of all incidents was 1.7 times higher. |
| 4 | Monsere et al. (2003) [53] | Cable Median Barrier | The cable median barriers were calculated to have prevented 105 possible median crossovers, according to the authors. |
| 5 | Donnell and Hughes (2005) [54] | Strong-post W-beam guardrail and concrete safety shape | In the median are the two most popular roadside barriers. |
| 6 | Donnell and Hughes (2005) [54] | Flexible three-strand cable and Brifen wire rope safety fence | In the United States, they're being used more often to avoid cross-median collisions. |
| 7 | Medina and Benekohal (2005) [55] | High-tension cable | The cable barrier systems seem to have outstanding overall efficiency when it comes to redirecting or stopping vehicles. |
| 8 | Murphy (2006) [56] | Cable with other types, including W-beam and weak-post barriers | Since the construction of cable median barriers, there has been a substantial decrease in the incidence of total crashes and the frequency of crossover crashes. |
| 9 | Arnold (2006) [57] | High-tension Brifen cable barrier | Following the construction of cable median barriers, descriptive statistics and pattern analysis revealed a marginally higher percentage of crossover crashes in the dark. |
| 10 | Sheikh et al. (2008) [58] | Cable Median Barriers | The severity of crashes decreased in areas where wire rope median barriers were built, although the overall number of crashes increased. |

| | | | |
|---|---|---|---|
| 11 | Agent and Pigman (2008) [59] | Brifen TL-4 and Trinity Cable Safety System (CASS) | The cable system was effective in redirecting errant vehicles, with the cable system failing just 0.9 percent of the time. |
| 12 | Hammond and Batiste (2008) [60] | Cable Median Barriers | According to the authors, while overall crashes increased in the after-period, fatal and serious injury crashes decreased significantly. |
| 13 | Mauga and Kaseko (2010) [61] | Raised Medians | Raised medians were found to effectively minimize crash frequency and severity. |
| 14 | Schultz et al. (2011) [62] | Raised Medians | The findings showed that raising medians reduces overall crash frequency by 39%. |
| 15 | Stolle (2012) [63] | Cable Median Barrier | The Safence 4-cable median barrier had the lowest rate of high-tension device intensity. |
| 16 | Alluri et al. (2015) [64] | Cable Median Barrier | The findings show that in real-world situations, cable median barriers effectively avoid the majority of median crossover crashes. |
| 17 | Zou and Tarko, (2016) [65] | Cable Median Barrier | Cable barriers placed on the far-side edge of a median were less likely to redirect vehicles back into traffic compared to those installed on the near-side edge, a result that aligned with expectations. |
| 18 | Srinivasan et al. (2017) [66] | Cable Median Barriers | According to the results of the report, the installation of cable median barriers reduced head-on, opposite-direction sideswipe, and cross-median collisions. |
| 19 | Nightingale (2017) [67] | Cable Median Barrier | While the use of a median cable barrier can help to reduce fatal and serious injuries caused by multi-vehicle cross-media collisions, it comes at a price. |
| 20 | Kim et al. (2018) [68] | Raised Medians | Raised medians were found to effectively minimize crash frequency and severity. |
| 21 | Yücel et al. (2018) [69] | Concrete Barrier | To improve traffic safety at medians, a new single-sided concrete barrier has been built. |
| 22 | Yücel et al. (2018) [69] | Steel Barrier | A highway vehicle impacting the barrier and accessing the tunnel faces a safety danger due to a lack of sufficient distance behind the barrier and the existence of a steep slope. |

## 2. 3 Case Study

Several studies have been performed on the safety and efficiency of cable-median barriers. Ray et al. (2009) [70] have thoroughly documented the development of median barrier guidelines, as well as their safety results, state policies, and summaries from pioneering states. The output of cable median barriers has also been compiled by the authors. Based on median-related crashes in some states, a before-and-after safety assessment of cable-median barriers was conducted. The percentages of errant vehicles prevented from (i) crossing the cable median barrier, i.e., barrier crossover, and (ii) crossing the median, i.e., median crossover, are used to determine the efficacy of the cable median barrier in this case study. The study investigated how median-related crashes changed over time, median crossovers, and site-specific evaluations based on vehicle type and crash severity. The overall median crossover rate was significantly reduced after the implementation of cable median barriers.

## 3 Results and Discussions

The literature review highlights that these barriers generally aim to reduce the severity of cross-median crashes, although their impact on overall crash frequency can vary. In terms of minimizing the magnitude of median crossover collisions, characteristic cable barriers are thought to be the most adaptable and forgiving. Cable barriers, in particular, have been shown in several studies to be effective in preventing median crossover crashes and reducing the severity of collisions. The term "deterring median" refers to an artificial median that can be thrown out in the event of a sudden and unpredictable event (emergency) that requires urgent action to avoid disaster.

### 3. 1 Classification and Safety Performance of Median Types

Depressed, Closed, Raised, Painted, or Flush are the four basic types of medians, with the following categories: Traversable (Flush) and Non-Traversable (Barrier and Deterring). Whether elevated, depressed, or flush, a traversable median is a visible separation without any physical barrier that can be crossed with comfort and ease. Before turning right from the street or after turning right onto the road, flush medians may be used to slow down and wait for a traffic break. Traversable medians, including flush and painted medians, provide a separation between opposing traffic flows. The literature suggests varying impacts on safety. For instance, research has explored the safety implications of different traversable median widths. On a street or road, a non-traversable median is a physical barrier that divides opposing vehicular traffic. Painted medians, a type of traversable median, have been studied for their safety benefits, particularly in terms of crash mitigation. Whittaker (2012) [36] found safety benefits from installing 1m wide continuous painted median strips. Regarding non-traversable medians, concrete barriers are known for their low life-cycle cost, safety efficiency, and relatively maintenance-free characteristics, despite their relatively high initial construction cost. Semi-rigid barriers are made up of interconnected metal railing parts braced by posts and blocks, and are often known as guardrails or guiderails. Non-traversable medians, such as concrete, steel, and cable barriers, physically separate opposing traffic.

### 3. 2 Performance Evaluation of Cable Median Barriers

Based on the case study undertaken in this study, Figures 7 and 8 show the annual cross-median crash frequency before and after cable median barriers were installed in each province. Ray et al. (2009) [70] contain the initial research from which these figures were derived. According to the figures, the percentage drop in fatal cross-median crashes ranged from 43 percent to 100 percent. Most of the states that have registered a 100 percent decrease have fewer miles of cable median barriers or have only recently built cable median barriers. Also, since the figures do not account for annual traffic growth or the occurrence of unreported collisions, the percent drop in cross-median crash frequencies is likely underestimated. The efficiency of cable median barriers in avoiding cross-median crashes is shown in Table 4. The percentage of vehicles controlled by the cable median barrier is used to measure the effectiveness. In all of the nations, the effectiveness rate was greater than 90%. To put it another way, more than 90% of vehicles colliding with the cable median barrier do not pass to the other side. The case study's findings indicated that cable median barriers are very effective in preventing cross-median crashes (with effectiveness rates exceeding 90%), supporting the conclusions drawn from the comprehensive literature review, which also emphasised their ability to reduce the severity of median crossover crashes. To more accurately assess the impacts of cable-median barrier construction and guarantee that the findings were not influenced by other unrelated collisions, the before-and-after study was limited to median-related incidents (i.e., crashes including vehicles leaving the travel lane toward the median). The high efficiency of cable barriers in preventing crossover crashes, as confirmed in the case study, suggests that they are a valuable tool for reducing severe crashes on high-speed roadways. However, the literature also indicates that an increased number of crashes may happen after the installation of cable median barriers. Therefore, design considerations should balance the reduction in cross-median crashes with possible increases in overall crash frequency. Further research is needed to optimize cable barrier design and location to maximize their safety benefits.

### 3. 3 Limitations and Future Research Directions

While this review provides a wide-ranging overview of median characteristics and their effect on safety performance, it's important to acknowledge the limitations of the existing review. Many studies focus on specific median types, such as cable barriers, and the comparison of all available median solutions. Furthermore, confounding factors like roadway geometry, traffic volume, and weather conditions, which can significantly influence crash rates, are not always controlled for in the research. The case study presented herein, while informative, is also subject to limitations, as it did not account for annual traffic growth or the occurrence of unreported crashes. Future research should arrange the use of standardized methodologies to enhance comparability across studies. There is also a need for research that investigates the interactive effects of median design with other roadway elements.

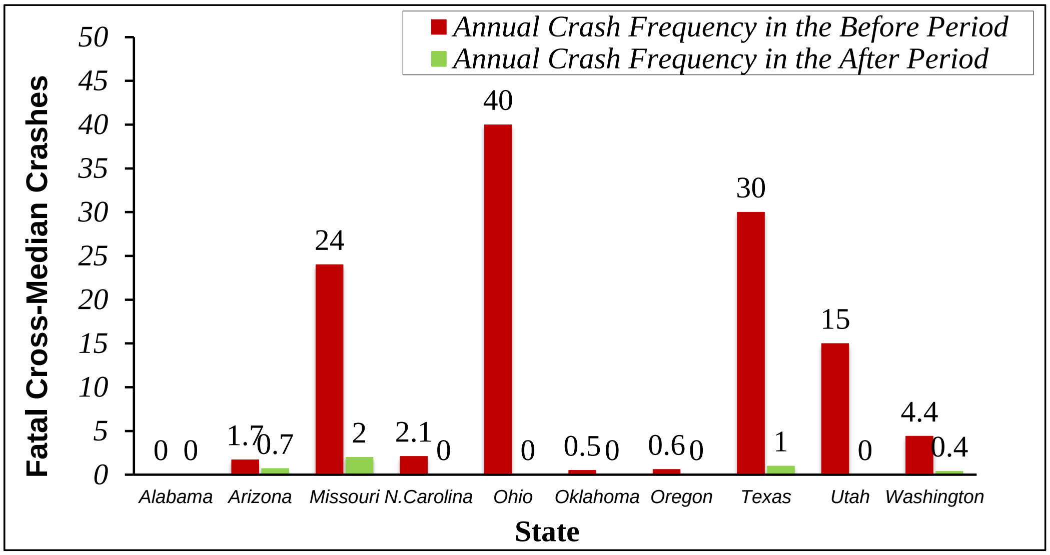


**Figure 7:** Fatal Cross-Median Crashes before and after the Installation of Cable Median [70]

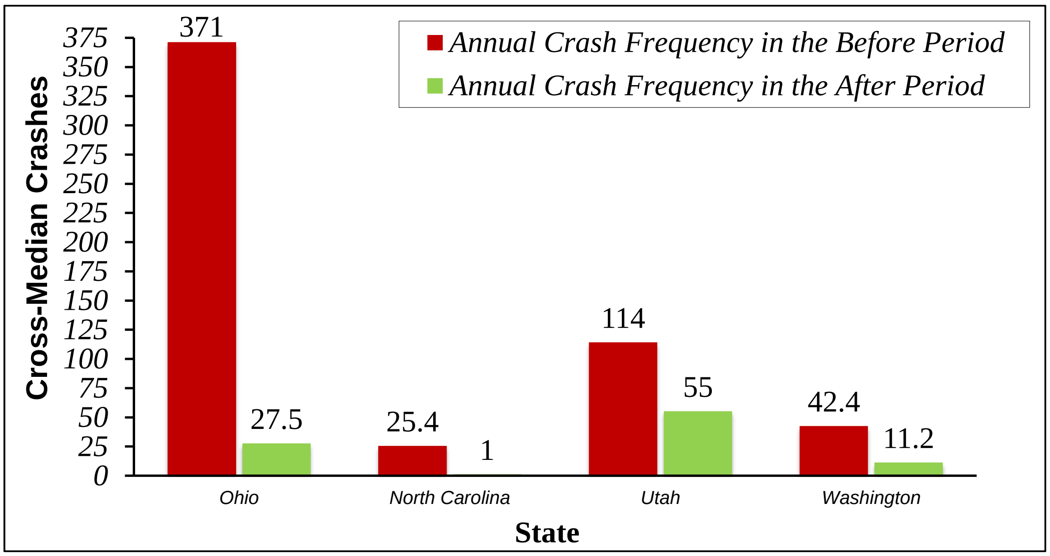


**Figure 8:** Cross-Median Crashes before and after the Installation of Cable Median [70]

**Table 4:** Reduction in Cross-Median Crashes After the Installation of Cable Median [28].

| State | Percent Reduction % |
|---|---|
| Alabama | 43 |
| Arizona | 59 |
| North Carolina | 92 |
| Ohio | 100 |
| Oklahoma | 100 |
| Oregon | 100 |
| Texas | 97 |
| Utah | 100 |
| Washington | 91 |

## 4 Conclusion

In conclusion, this review highlights the significant impact that median barrier characteristics have on roadway safety and overall crash performance. The key goal of this review paper is to evaluate the protection of road median barrier systems built on restricted access facilities for different purposes (such as freeways and expressways).

- Based on a comprehensive literature review, it is concluded that the characteristic cable barriers are thought to be the most adaptable and accommodating in terms of reducing the severity of median crossover collisions.
- The majority of the research conducted in this analysis study focused on this form of median barrier. This may be because cable barriers are typically less costly to construct than rigid and semi-rigid barriers.
- The outcomes of the case study revealed that the study centered on finding median-related crashes for the before-and-after research. A median-related crash occurs when an errant vehicle exits the designated travel lane to the left (i.e., toward the median) at any point throughout the collision.
- The study centered on detecting crossover collisions and the crash effects of vehicles reaching the barrier for crossover research. To more accurately assess the impressions of cable median barrier construction and guarantee that the findings were not influenced by other unrelated collisions, the before-and-after study was limited to median-associated incidents (i.e., crashes including vehicles leaving the travel lane toward the median).

### Table of Symbols

The following abbreviations are used in this manuscript:

| Symbol | Definition |
|---|---|
| *FDOT* | Florida Department of Transportation |
| *AMFs* | Crash Modification Factors |
| *HSM* | Highway Safety Manual |
| *NHA* | National Highways Authority |


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### Authors contribution

Conceptualization, Jiman Naji Hasan and Nasreen Ahmed Hussein; methodology, Jiman Naji Hasan and Nasreen Ahmed Hussein; software, Jiman Naji Hasan and Nasreen Ahmed Hussein; validation, Jiman Naji Hasan and Nasreen Ahmed Hussein; formal analysis, Jiman Naji Hasan; investigation, Jiman Naji Hasan and Nasreen Ahmed Hussein; resources, Nasreen Ahmed Hussein; data curation, Jiman Naji Hasan and Nasreen Ahmed Hussein; writing original draft preparation, Jiman Naji Hasan; writing review and editing, Jiman Naji Hasan and Nasreen Ahmed Hussein; visualization, Nasreen Ahmed Hussein; supervision, Nasreen Ahmed Hussein; project administration, Jiman Naji Hasan and Nasreen Ahmed Hussein; funding acquisition, Jiman Naji Hasan and Nasreen Ahmed Hussein.

### Conflict of interests

The authors declare no conflicts of interest.

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