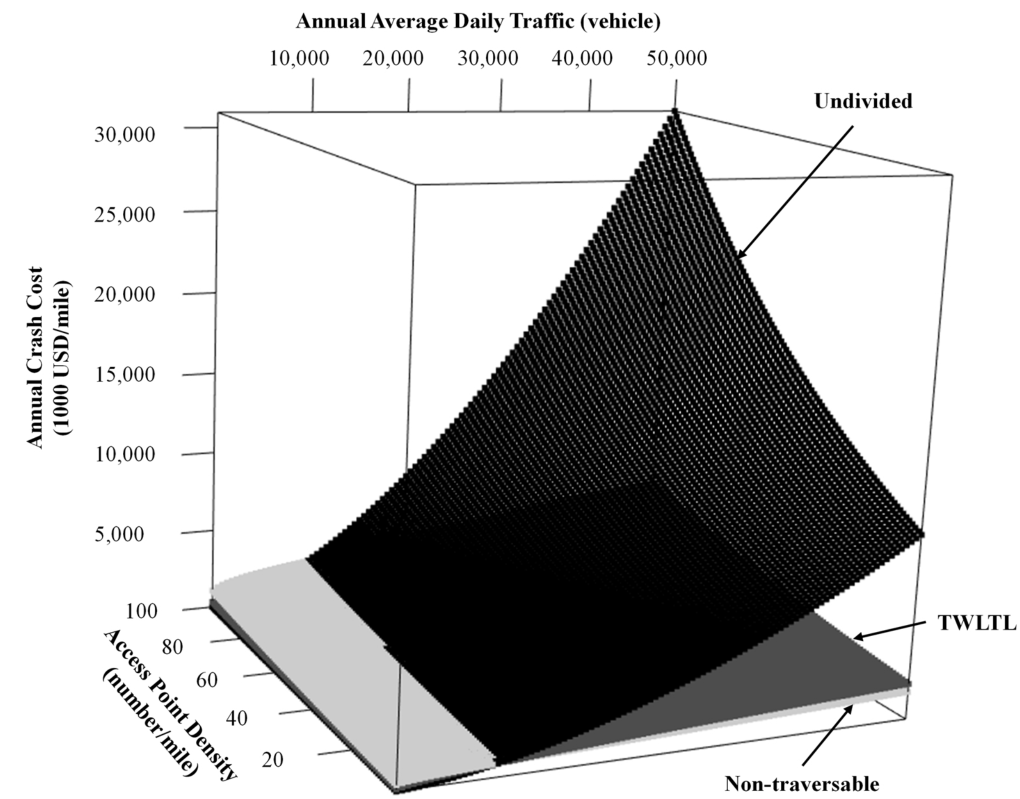
JOINT TRANSPORTATION RESEARCH PROGRAM
INDIANA DEPARTMENT OF TRANSPORTATION AND PURDUE UNIVERSITY

A Study of Suburban Arterial Safety Performance Based on Median Type



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SPR-4736 • Report Number: FHWA/IN/JTRP-2025/07 • DOI: 10.5703/1288284317848

RECOMMENDED CITATION

Tarko, A. P., Guo, Q., Narayanan, P. D., Romero, M. A., & Bandaru, V. K. (2025). *A study of suburban arterial safety performance based on median type* (Joint Transportation Research Program Publication No. FHWA/IN/JTRP-2025/07). West Lafayette, IN: Purdue University. https://doi.org/10.5703/1288284317848

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NOTICE

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No. FHWA/IN/JTRP-2025/07	**2. Government Accession No.**	**3. Recipient's Catalog No.**
4. Title and Subtitle A Study of Suburban Arterial Safety Performance Based on Median Type		**5. Report Date** February 2025 **6. Performing Organization Code**
7. Author(s) Andrew Tarko, Qiming Guo, Priya Darshini Narayanan, Mario Romero, and Vamsi Krishna Bandaru		**8. Performing Organization Report No.** FHWA/IN/JTRP-2025/07
9. Performing Organization Name and Address Joint Transportation Research Program Hall for Discovery and Learning Research (DLR), Suite 204 207 S. Martin Jischke Drive West Lafayette, IN 47907		**10. Work Unit No.** **11. Contract or Grant No.** SPR-4736
12. Sponsoring Agency Name and Address Indiana Department of Transportation (SPR) State Office Building 100 North Senate Avenue Indianapolis, IN 46204		**13. Type of Report and Period Covered** Final Report **14. Sponsoring Agency Code**

15. Supplementary Notes

Conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

16. Abstract

Suburban arterial roadways must serve two conflicting road functions: regional mobility and access to the abutting land. The potential for conflicts between traffic passing through and traffic accessing road from the neighboring areas could raise safety concerns. Selecting an adequate cross-section is among important decisions that road designers and traffic engineers consider when mitigating the mentioned conflict. The following three alternative treatments offer different access control levels: undivided cross-section with no median, two-way left-turn lane instead of a typical median, and non-traversable median. The frequency of access points and the selected median treatment option should be commensurate.

Although it is known that access control usually leads to better safety performance, selecting median treatment under certain operational conditions requires careful considerations that must be associated with a properly selected speed limit. It is a challenging task that is not well covered in the existing literature. Drivers' perception of crash risk affects their speed choice and, consequently, the speed limits selected by traffic engineers. On the other hand, the posted speed limits affect both drivers' speed selection and road safety. Properly estimating this complex relationship is important for providing adequate guidance on median treatment selection.

To properly compare the safety performance of different median treatments on suburban arterial roads, and to provide practical median treatment selection guidance for traffic engineers, this study analyzed roadway geometrics, traffic and crash data along 200 road segments across Indiana by applying simultaneous equations to address the endogeneity problem mentioned earlier. A comprehensive crash cost-oriented analysis framework was applied to help identify the most appropriate median treatment among the three types evaluated.

Traffic volume, density of access points, speed limit, and median treatments on the road segments studied were found to significantly affect safety performance. It was also confirmed that the operational conditions affect the crash cost and, consequently, they influence the choice of the median treatment. The study results were used to generate a convenient set of tables and figures to support a median treatment selection. The results presented and implementation suggestions are meant to help end users economically assess the safety performance of median treatments on suburban arterials to select the best alternative.

17. Key Words median, suburban arterial, safety performance, median treatment	**18. Distribution Statement** No restrictions. This document is available through the National Technical Information Service, Springfield, VA 22161.

19. Security Classif. (of this report) Unclassified	**20. Security Classif. (of this page)** Unclassified	**21. No. of Pages** 77 including appendices	**22. Price**

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

EXECUTIVE SUMMARY

Introduction

Suburban arterial roadways serve two conflicting functions: (1) mobility to pass traffic through the abutting area and, to some extent, and (2) accessibility to allow local traffic from neighboring areas access the road. Among design alternatives that road designers and traffic engineers consider, selecting the median type is among the most important design decisions. Three alternative median types (undivided cross-section, two-way left-turn lane, and non-traversable median) offer different access control levels on the road. Although higher control levels of access usually lead to better safety performance, the lower control level median treatments might perform equally well under certain operational conditions. To quantify the relationship between median treatments and their safety outcomes under various operational conditions, this project used advanced statistical analysis to analyze roadway geometrics (median treatments), traffic, and safety along 200 suburban and urban road segments across Indiana. A comprehensive crash cost-oriented analysis framework was applied to help identify the most appropriate median treatment under the land use and traffic conditions.

Findings

On the methodology side, the challenging endogeneity between crashes and speed limits was identified and treated with simultaneous equations, in which the crash counts and speed limits were assumed to be correlated one with another.

On the knowledge side, the important risk factors that significantly affect arterial road safety were quantified in the developed models.

1. Traffic volume increased crash frequency, while the road geometric standards, represented with a speed limit, generally had a positive effect on safety.
2. The density of roadside access points via driveways and unsignalized intersections was found to increase crash frequency.
3. Median treatments affected crash frequency to an extent that varied across various local conditions, including traffic volume, speed limit, and access point density.
4. Six-lane roadways had drastically fewer severe crashes when a median was a non-traversable type.

Implementation

The estimated statistical models were applied to obtain results in convenient formats for the end user—crash cost tables, graphs to select the median treatment, and tables that reveal alternatives closest to the best one.

1. *Crash Cost Tables:* A comprehensive crash cost-oriented analysis framework was applied to transform the estimates of the models into comparable expected crash cost per mile for the three investigated median treatments. The crash cost tables with the expected crash costs per mile for three median treatments, access point density (multiples of 10 access points/mile), and AADT (multiples of 2,000 veh/day) were calculated under different speed limits (30 mph, 35 mph, and so on). These tables provide the expected crash costs for the three median treatments under various conditions and for a direct comparison of alternative median treatments.
   - *Selection Graphs:* A set of 2D graphs (AADT on x-axis, access point density on y-axis) for individual speed limits (30−55 mph) were developed to facilitate a convenient selection of the median treatment with the lowest cost.
2. *Comparable Alternatives Tables:* Considering the randomness of crashes and the associated uncertainty of the estimates, a treatment may be considered comparable to the best one if its associated crash cost is not significantly higher than the lowest cost. Following this idea, tables are provided that list median treatments that are performing slightly worse than the best one within a user-selected margin.

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1. INTRODUCTION

Suburban arterial roadways with high traffic volumes, high speeds, and dense commercial drive density in their vicinity must serve two conflicting road functions: mobility and access to abutting land. The considerable potential for conflicts between traffic passing through and traffic accessing or leaving the abutting land demands that these facilities receive careful consideration from designers, traffic engineers, planners and safety analysts. One important consideration is selecting a suitable median type. This decision coupled with selecting a suitable level of access control, affects the traffic interaction between the arterial through traffic flows and the accessing/returning traffic flows. In turn, this interaction is a major factor of the risk of collision along the arterial. The purpose of this study is to investigate the safety performance of different median treatments and provide INDOT with guidelines that will in turn assist design engineers with proper median selection on arterial roadways.

From the design perspective, in chapter 45 of the *Indiana Department of Transportation—2013 Design Manual* (INDOT, 2013a) describes the following four types of medians in arterial road cross-sections:

1. flush median (Figure 1.1),
2. flush median with concrete barrier (Figure 1.2),
3. raised median (Figure 1.3), and
4. depressed median (Figure 1.4).

The traversable flush median design is recommended where frequent intersections and access points are expected. Moreover, this design allows placing additional left-turn lanes on approaches to intersections and continuous two-way left-turn lanes (TWLTL) on segments between intersections. The other three cross-section types (flush with concrete median barrier, raised, and depressed) are typically used in suburban areas and on major arterials in urban areas. All three designs restrict crossing the median. Therefore, these three design alternatives are combined in this study into a single case called non-traversable median and considered as a single type. The undivided cross-section design is the third alternative, which is considered where the right of way is insufficient. This design can be found in suburban areas with relatively low-speed limits. For the purpose of this study, median treatments used on suburban arterials are classified into three types:

1. undivided cross-section (undivided),
2. TWLTL, and
3. non-traversable.

There are past studies that investigated the effects of these median treatments on arterial traffic safety. Consequently, some existing design manuals provide crash reduction factors or criteria helpful in selecting a median treatment from several alternatives. However, the mentioned studies lacked consideration of the

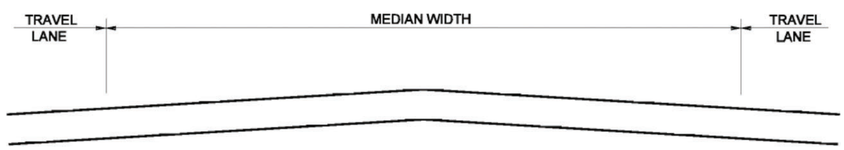


Figure 1.1 Flush median.

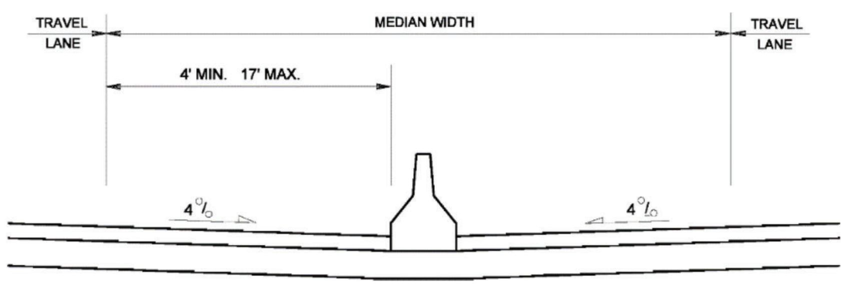


Figure 1.2 Flush with concrete median barrier.

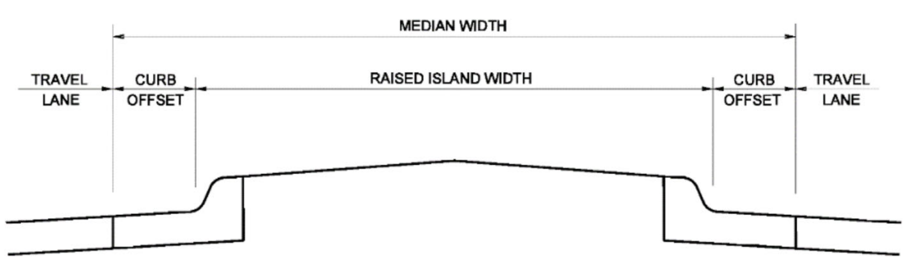


Figure 1.3 Raised median.

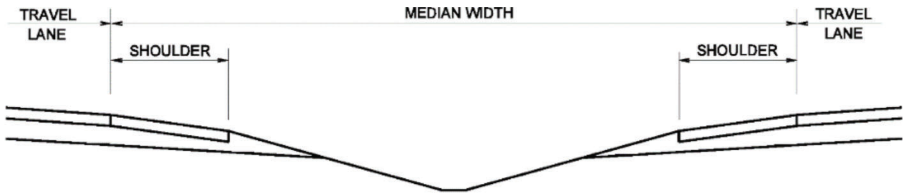


Figure 1.4 Depressed median.

complex reciprocal relationships between the observed safety and the engineering decisions. Consider the relationship between speed limits, driving behavior, and safety. On the one hand, traffic engineers typically set speed limits based on the 85th percentile speed estimated with field speed measurements. This observed speed choice by drivers is affected by safety perceived by them. Furthermore, speeds and their distribution reflected in the speed percentile affect the risk and severity of crashes. On the other hand, it might be that those crashes, particularly severe crashes, and their concentration on certain road segments trigger speed studies to set new speed limits there. Reducing speeds is among safety countermeasures recommended in safety management manuals. In addition, speed limit enforcement affects the speed of drivers while low speed limits themselves may induce enhanced risk perception among some drivers.

Consequently, safety as represented with reported crashes, posted speed limits, and observed drivers' speeds are related in multiple ways. Any attempt to statistically estimate the individual relationships between any two quantities in isolation from the other relationships will lead to biased estimates of these relationships and the effects of other factors.

Selecting the most appropriate median treatment among the three considered based on the local traffic and geometric conditions would be a beneficial and practical tool for traffic engineers and road designers. Such a selection guide should be the result of a comprehensive economic analysis of both benefits and costs. There are cost records from past projects and well-established traffic models that could be used for this purpose. The only remaining and most challenging part is estimating the expected safety benefits. This need is addressed in the presented study through applying a crash cost-oriented evaluation framework. The crash frequency simultaneous equations estimated by severity give valuable insights into the safety performance. In the next step, the crash costs associated with the considered median treatments could be estimated to provide end users with estimated crash costs by median treatment for the same conditions. These alternative estimates would support a median treatment selection for the considered conditions.

The remainder of the report is organized into the following chapters.

- Chapter 2: Literature Review
- Chapter 3: Research Problem
- Chapter 4: Data Preparation
- Chapter 5: Statistical Analysis
- Chapter 6: Model Implementation
- Chapter 7: Conclusions
- References
- Appendices

2. LITERATURE REVIEW

This chapter provides an overview of past research efforts regarding performance of various median treatments both with and without access management. As mentioned earlier, non-traversable medians include flush medians with a concrete barrier, raised medians with a steep-faced curb, and depressed medians; the last case frequently includes a turf-covered area inside.

The Indiana study JTRP-98-7 (Brown et al., 1998) highlighted the negative safety impact of high density of driveways on busy urban arterials. The study focused on conventional continuous medians, and it revealed the need for further guidance on selecting appropriate median types, particularly, for suburban arterials. Such guidance should be based on local land use, density, access needs, traffic volumes, and desired speed limits. Table 2.1 taken from the *Access Management Manual* (AECOM Transportation, 2009) illustrates this need. It shows a lack of clarity about optimal median treatments when only traffic volumes are considered. It indicates that both continuous two-way left-turn lane (TWLTL) and non-traversable medians reduce crashes by 35%, but a non-traversable median can reduce crashes by 15% to 57% on 4-lane roads and by 25% to 50% on 6-lane roads when replacing TWLTL.

On the other hand, the *Indiana Department of Transportation—2013 Design Manual* (INDOT, 2013b) recommends certain median types, including TWLTL, based on the arterial traffic volume.

- On a 2-lane roadway, TWLTL is beneficial for an AADT between 5,000 and 12,500.
- On a 4-lane highway, TWLTL is advantageous for an AADT between 10,000 and 25,000.
- For AADT over 25,000, a non-traversable median is recommended, particularly for 6-lane highways.
- Pedestrian crossing volume is also a crucial factor due to the lack of pedestrian refuges in TWLTL designs.

The inconsistencies among the existing recommendations call for their revision for Indiana conditions. Literature (discussed in subsequent sections of this chapter) shows that factors such as the number of traffic lanes, abutting land development, access point density, and speed limits are shown to have an impact on safety of arterial roads. Thus, considering these safety factors in the postulated analysis is justified.

2.1 Comparison of Median Types

A regression analysis was done to compare safety performances of non-traversable median and TWLTL median treatments on road sections in Georgia (Squires & Parsonson, 1989). The authors' analysis shows that for four-lane sections, non-traversable medians were safer than TWLTLs in all the studied cases though the difference in crash rates decreased with the increase in the number of signals per mile. For six-lane road sections, TWLTLs were safer under specific conditions, namely at least 75 driveways of driveways per mile, two or fewer signals per mile, and no more than 5 or 6 approaches per mile (Squires & Parsonson, 1989).

Another study examined corridors in Texas that underwent the installation of non-traversable medians, transitioning from either undivided or TWLTL configurations (Eisele & Frawley, 2005). The findings indicated that the two corridors transitioning from a TWLTL to a non-traversable median experienced a 17% and 58% reduction in crash rate (crashes per MVMT), whereas the three corridors that were previously undivided experienced the 21% to 53% reduction in crash rate (Eisele & Frawley, 2005). Their report included a graph detailing crash types for a single corridor (Figure 2.1). However, data on crash types for the other corridors considered was not provided.

A before-and-after analysis was conducted to evaluate the safety effectiveness of non-traversable median over TWLTL (Schultz et al., 2007). Crash data on six corridors with access control (i.e., non-traversable medians or driveway consolidation) in 12 years were compared to five corridors that lacked access control. The authors concluded that the non-traversable median did not reduce the total crash rates but improved safety in terms of reducing high severity crashes, namely, fatal and injury crashes. The paper explained the methodology in detail for one site and mentioned that others were done in a similar manner but failed to provide details on the type of treatments applied at implementation sites.

A cross-sectional study of 71 four-legged unsignalized intersections in Florida showed that when compared to intersections having non-traversable medians with median opening, TWLTL lanes experienced 45% more crashes (Haleem et al., 2010). A negative binomial model with Bayesian updating reliability method was utilized to predict the number of crashes.

A before-and-after safety evaluation was conducted at 18 locations that were converted from TWLTLs to non-traversable medians (Alluri et al., 2012). The analysis was done based on data collected in 3-year to 5-year periods. Overall, the total crash rate across all locations was reduced from 3.618 crashes per million vehicle miles (MVM) to 2.523 crashes per MVM after median conversion, representing a 30.3% reduction in the total crash rate. The reductions in crash rate of

TABLE 2.1
Summary of research on the effects of various access management techniques

Treatment	Effect
Add continuous TWLTL	35% reduction in total crashes
Add non-traversable median	35% reduction in total crashes
Replace TWLTL with a non-traversable median	15%−57% crash reduction on 4-lane roads 25%−50% crash reduction on 6-lane roads

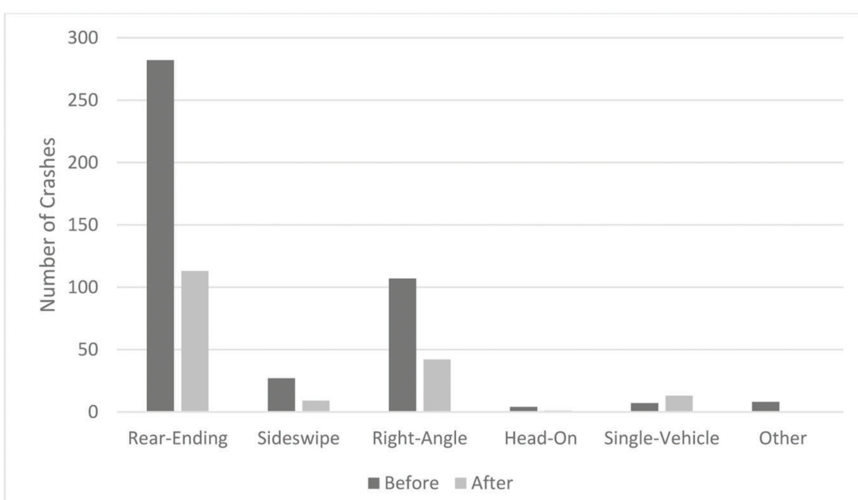


Figure 2.1 Texas avenue crash type summary (Eisele & Frawley, 2005).

rear-end, angle, left-turn, right-turn, and total crashes were statistically significant; the crash rate reductions for sideswipe, pedestrian, and bicycle crashes were statistically insignificant. In terms of crash severity, there was a statistically significant reduction in PD and injury crash rates, and no significant reduction in fatal crash rate was observed after median conversion (Alluri et al., 2012).

A multivariate zero-inflated binomial model (MVZIB) was used to analyze the crash frequencies on 1,506 directional urban midblock segments in Nebraska (Liu et al., 2018). The study deployed two model alternatives: random and fixed-parameter MVZIB models. The authors' models indicated that the presence of median of any type (TWLTL or non-traversable median) reduced the crash frequencies while features such as presence of a shoulder, on-street parking, one-way traffic, and lane width had no significant influences on the crash frequencies. As expected, the random-parameter MVZIB identified fewer safety factors than the MVZIB fixed parameter version, but it revealed segment-specific effects on different crash types (Liu et al., 2018).

2.2 Access Density

A study conducted on crashes related to driveways in Skokie, Illinois showed that over 60% of all driveway collisions and 75% of injury crashes on the studied 40 miles of major streets involved left turning maneuvers (Box, 1969). Driveways (residential, commercial, and industrial combined) on those streets on average experienced 0.13 crashes per year, however residential driveways experienced on average only 0.02 crashes per year. Further, a driveway on roads with median barriers experienced eight times fewer crashes annually than a driveway on roads without median barriers (Box, 1969).

McGuirk and Satterly (1976) analyzed crashes that occurred during 4 years on 100 Indiana roadway sections. They recommended countermeasures such as barrier medians, traffic signals, left-turn lanes, and left-turn prohibitions to reduce driveway crashes. This study further concluded that the number of driveway crashes per mile per year would decrease when one or more of the following conditions occurred (McGuirk & Satterly, 1976).

- The number of commercial driveways per mile was reduced.
- The number of through traffic lanes was reduced.
- The number of intersections per mile increased.
- The number of total driveways per mile was reduced.
- The arterial highway ADT was reduced.

Regardless of the median type, the crashes per million vehicle miles travelled (MVMT) were approximately 2.2 times higher for access densities exceeding 60 points per mile compared to access densities of 20 or fewer access points per mile (Gluck et al., 1999). Table 2.2 shows the crash rates by access density and median type in urban/suburban segments obtained in that study. Another study reported in (Eisele & Frawley, 2005) concluded that the crash rate tended to be higher where the number of access points per mile was higher while the crash-access density relationship was steeper on roadways without medians (Figure 2.2).

TABLE 2.2
Crash rates (crashes per MVMT) by access density and median treatment: urban/suburban segments (Gluck et al., 1999)

Access Density	Undivided	TWLTL	Non-Traversable
≤20	3.82	–	2.94
20.01–40	8.27	5.87	5.13
40.01–60	9.35	7.43	6.47
>60	9.55	9.17	5.40

A study of driveways along highways in Oregon (Avelar et al., 2013) revealed that roadside safety in urban areas was primarily affected by commercial and industrial driveways, while in rural areas, the effect of industrial driveways was stronger. Additionally, in rural areas clustered driveways tended to have fewer crashes compared to isolated ones (Avelar et al., 2013).

A study was conducted to learn the impacts of various access densities on the safety performance of major arterials in New Mexico using cluster analysis and a negative binomial model (Chen et al., 2018). The analysis results demonstrated the piecewise relationship and verified that access density imposed heterogeneous influence on crash rates under different access density ranges. The crash rate increased as the access density increased at a certain rate of 0.115 when the access density was lower than 20 points/mi. Further, the crash rate varied without an obvious increase trend when the access density was between 20 points/mi and 47 points/mi. In the third access density range between 47 points/mi and 82 points/mi, the crash rate increased at a rate of 0.251. These results indicated a faster increase rate in the third range of access densities than in the previous ranges (Chen et al., 2018).

2.3 Median Openings

A study of eight arterial segments in Michigan (Taylor et al., 2001) showed that replacing bi-directional median crossovers with directional ones resulted in over 30% reduction in both total crashes and crashes with at least one injury. It was accomplished by reducing the number of conflict points and simplifying the traffic situation.

Another study evaluated the safety and operation of the median openings nearby signalized intersections and determined the variables that influence the safety performance on arterials with median openings (Maryam Mousavi et al., 2022). The results indicated that the recommended minimum distance from a median opening to its adjacent signalized intersection depends on the number of conflicting driveways, median opening type, and the number of arterial lanes.

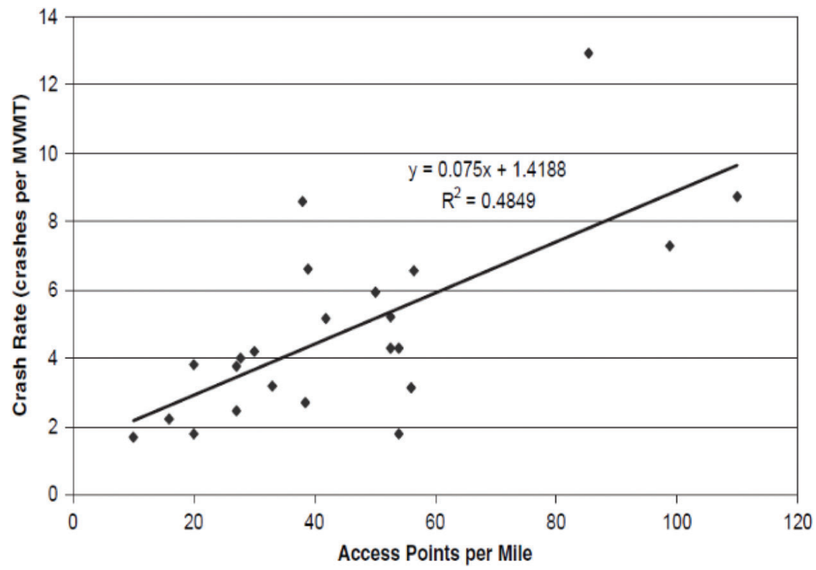


Figure 2.2 Relationship between access point density and crash rates (Eisele & Frawley, 2005).

Moreover, safety is affected by the median opening type, the number of arterial lanes, and the average daily traffic (Maryam Mousavi et al., 2022).

3. RESEARCH PROBLEM

3.1 Research Objective

The primary objective of this study is to assist in selecting median treatment in reconstruction or new construction projects with the expectation to lower the crash risk at a given land development and annual average daily traffic (AADT). This guidance is in the form of charts and tables that provide driveway density thresholds for different median configurations under a certain number of lanes, AADT, and speed. This assistance is needed to identify arterial roads where safety could be improved by replacing two-way left-turn lanes (TWLTLs) with a non-traversable median with limited openings. There are also possible scenarios where inserting a TWLTL would be beneficial for safety by reducing local traffic circulation.

3.2 Research Scope and Method

The scope of work includes the following three median-focused cross-section design cases that are considered in reconstruction or new construction of suburban arterial roads: (1) undivided, (2) TWLTL, and (3) non-traversable median.

To comprehensively analyze the safety performance of these three median treatments, first, a representative sample of suburban arterials were selected across Indiana. Second, the selected sections between major intersections on these arterials were divided into shorter and approximately homogeneous segments (similar land use and accessibility) but sufficiently long enough for proper operation of the analyzed types of medians. Third, data related to the geometry, operational, and traffic features were collected for these segments. Fourth, crash density by severity levels were estimated using sets of simultaneous equations. Considered risk factors include density of driveways and unsignalized intersections, number of continuous lanes, AADT, segment length and speed limit. Finally, the developed models were used to estimate the expected crash cost per mile under multiple scenarios defined with combinations of the considered safety factors. The safest median treatments for considered scenarios were summarized on graphs and tables to be used by end users.

4. DATA PREPARATION

4.1 Data Acquisition

State-administered suburban arterial road sections (100 miles in total) across Indiana with one of the three studied median treatments were used to investigate the safety performance of these roads. The selected road sections were then split into smaller segments stretching between consecutive signalized intersections. The obtained segments were then further divided to ensure homogeneity in terms of the following characteristics: posted speed limit, median treatment, and density of access points (driveways and unsignalized intersections).

To accomplish the homogeneity of study segments, intersection approaches with altered road cross-sections were removed. For this purpose, an intersection approach with a left-turn turning lane was assumed up to the left-turn lane taper's upstream end. In cases of no taper, the approach end was assumed to be between 150 feet and 250 feet upstream of the stop line (Figure 4.1). This distance was determined based on an obvious change in the approach cross-section or other inconsistency, such as, a change in median type from TWLTL/undivided to non-traversable median. On the

200 segments studied, 46 miles of the intersection impact areas were removed in total. Thus, 54 miles of road segments were left for further analysis.

Marking the end points of the segments studied was facilitated with a software tool developed by the Center for Road Safety (CRS) at Purdue University. The defined end points of analyzed segments were imported into ArcGIS and the lengths of both studied segment lengths and intersection impact lengths were computed using the linear distance measuring tool. Google Maps' satellite and street views were used to collect features such as number of lanes, type of median treatment, etc. The location of driveways and unsignalized intersections were marked using the same software that was developed for data acquisition.

4.2 Variables

4.2.1 Segment Length

Segment length is the distance between the end points of a segment along the roadway measured with GIS tools. The distribution of the segment lengths by median type is shown in Table 4.1.

4.2.2 Median Treatment

The median type in a considered segment was identified using the street-view tool in Google Maps and was appended with the software that was developed by CRS. The three types of cross sections considered as part of this study are as follows:

1. undivided (Figure 4.2),
2. continuous two-way left-turn lane (TWLTL) (Figure 4.3), and
3. non-traversable (Figure 4.4).

4.2.3 AADT

The AADT of the main road and the crossroad for the years 2015 to 2022 was obtained from INDOT's yearly shapefiles. The example distribution of 2019 AADT values for undivided, TWLTL, and non-traversable median alternatives are shown in Figure 4.5, Figure 4.6, and Figure 4.7, respectively.

4.2.4 Posted Speed Limit

The posted speed limit information was extracted for each segment from the posted speed limit shapefile provided by INDOT and verified by the research team using the street view feature available in Google Maps. The distributions of posted speed limits are shown in Figure 4.8.

4.2.5 Number of Through Lanes

The number of through lanes on each segment was noted manually using the satellite view of Google Maps. The distribution of number of through lanes is shown in Figure 4.9.

4.2.6 Access Points

Access point refers to an element of a roadway network that allows vehicles to access adjacent parcels of land from a given roadway. Access points can range from large, complex intersections to simple, unpaved field entrances. For the purposes of this research, access points were primarily divided into two types.

- *Driveways*: Access points that provide access to adjoining residences or businesses or parking lots (Figure 4.10).
- *Unsignalized intersections:* Intersections with minor collector or local roads or private roads that allowed

Figure 4.1 Segment definition (IndianaMap, 2024).

TABLE 4.1
Distribution of segment lengths

Median Type	Number of Segments	Minimum (ft)	Maximum (ft)	Average (ft)	Std. Dev. (ft)	Total (miles)
Undivided	33	368.25	3,623.46	1,560.47	828.65	9.75
TWLTL	86	224.25	4,060.85	1,453.21	853.55	22.29
Non-Traversable	81	173.65	4,265.79	1,418.51	1,003.42	21.76

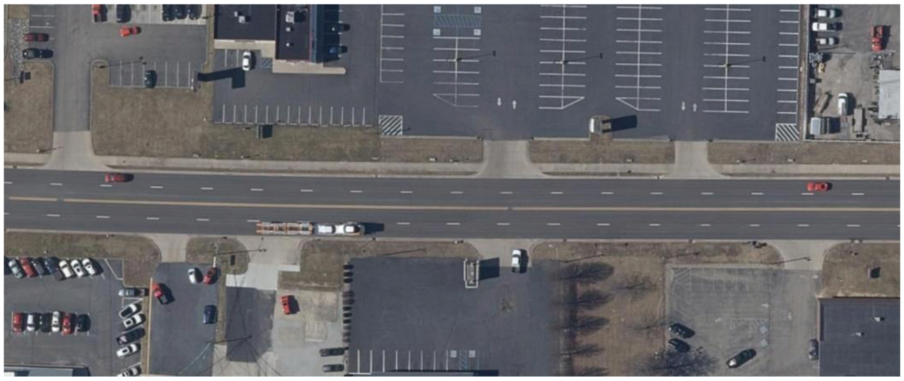


Figure 4.2 Example of undivided median (IndianaMap, 2024).

Figure 4.3 Example of TWLTL (IndianaMap, 2024).

Figure 4.4 Example of non-traversable median (IndianaMap, 2024).

access to residences, commercial/industrial establishments, and other developments (Figure 4.11).

The location of both the types of access facilities was marked using the software that was developed for data acquisition. The distribution of driveway density and unsignalized intersection density are shown in Figure 4.12 and Figure 4.13, respectively.

4.2.7 Access Points Directionality

Access points are classified into the following three types based on how the traffic flows through them.

- *One-directional access points:* These access points only allow entry into the abutting land or exit the abutting land but not both. An example of this is shown in Figure 4.14.

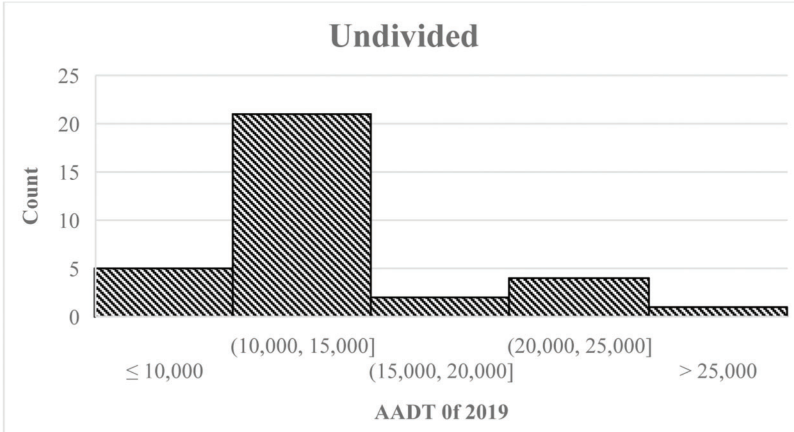


Figure 4.5 Distribution of AADT: 2019 for undivided.

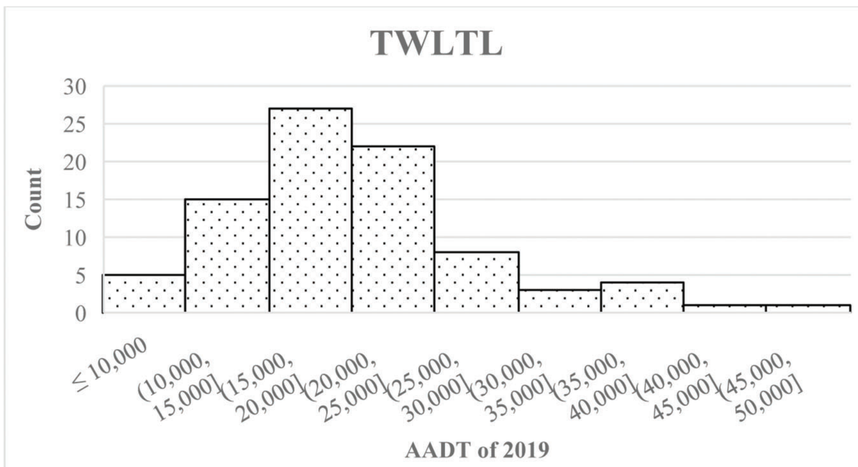


Figure 4.6 Distribution of AADT: 2019 for TWLTL.

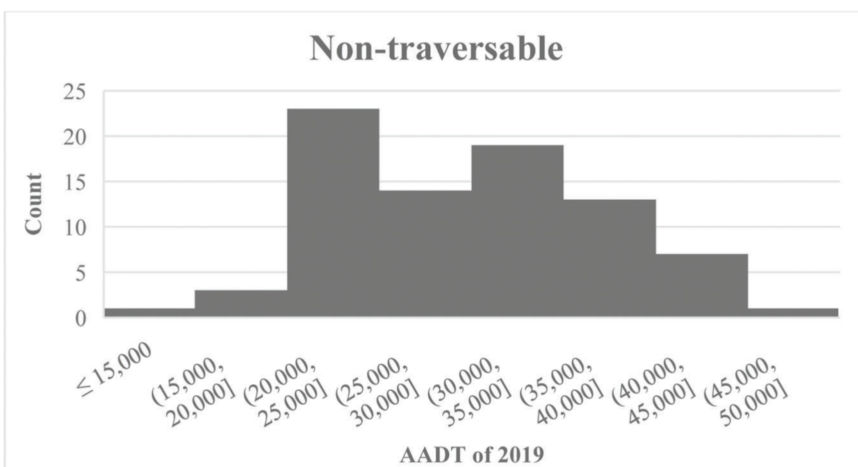
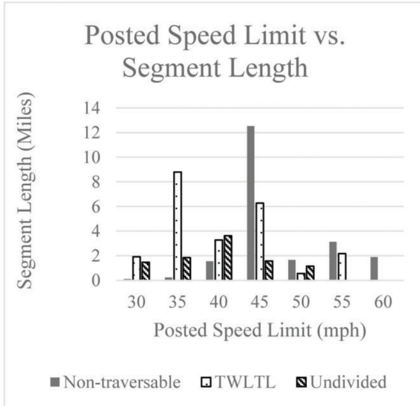


Figure 4.7 Distribution of AADT: 2019 for non-traversable.

- *Two-directional access points:* These access points permit both entry and exit from the abutting land. An example of this type is shown in Figure 4.15.
- *Two-directional access points with islands:* In the case of two directional access points, raised islands are deployed for separating the opposing traffic streams or to provide channelization and prevent certain turning maneuvers. A distinction is made for such access points. Figure 4.16 shows an access point of this type where there exists a raised island to separate the two opposing streams.



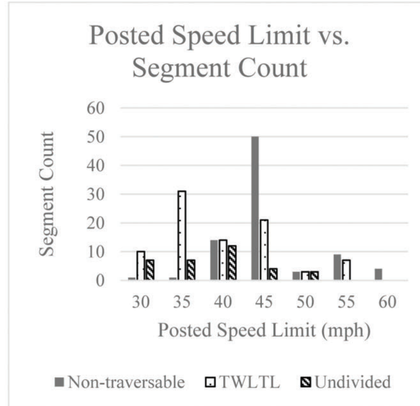
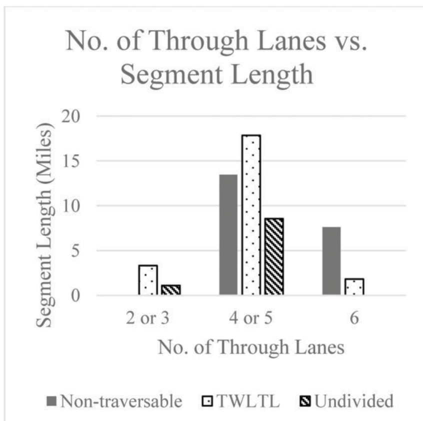


Figure 4.8 Distribution of posted speed limit.



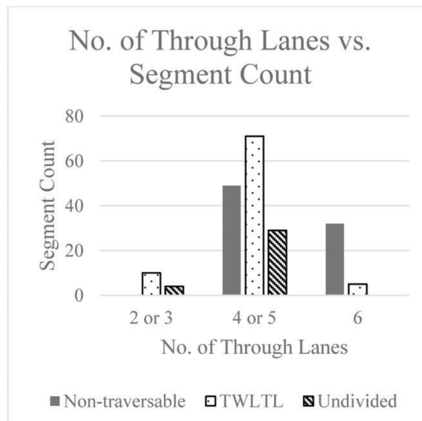


Figure 4.9 Distribution of number of lanes (on major road).

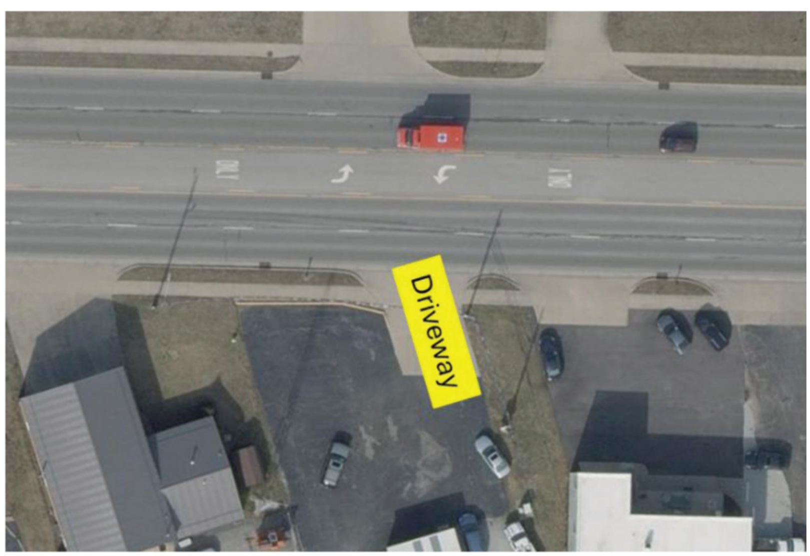


Figure 4.10 Example driveway (IndianaMap, 2024).

Figure 4.11 Example of unsignalized intersection (IndianaMap, 2024).

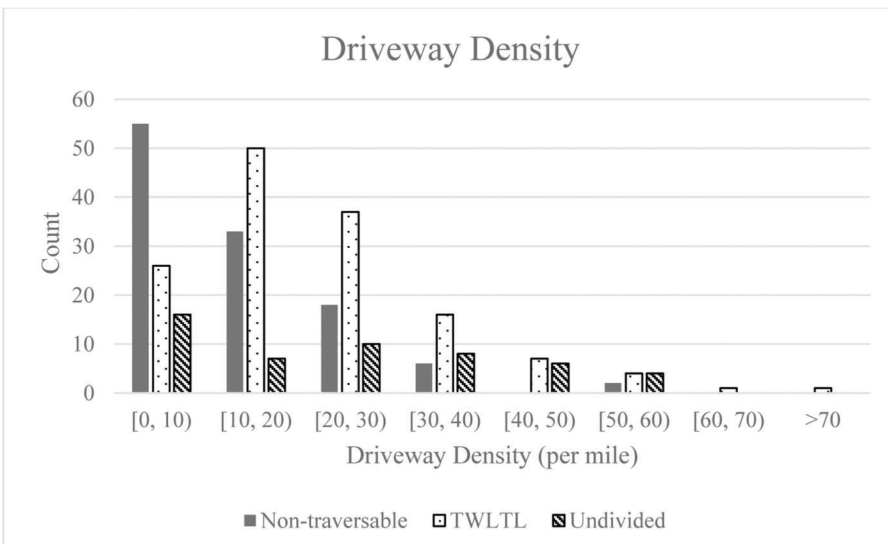


Figure 4.12 Distribution of driveway density.

The geometry of the raised island discourages left turn maneuvers for vehicles exiting Production Drive and entering Rockville Road.

4.2.8 Access Points Entry Marking

Depending on the markings of an access point, entry into adjacent land development via a left turn maneuver may be prohibited. Three types of marking were investigated in this study.

1. *Continuous Median:* In this type of marking, there exists a physical barrier of some kind preventing left turn maneuvers into the adjacent land. Figure 4.17 depicts an access point where entry via left turn maneuver is prohibited by the presence of a non-traversable median.
2. *Continuous Centerline:* In this type of marking, there does not exist a physical barrier, but there exists a continuous centerline (two yellow solid lines) on the main road. The access point depicted in Figure 4.18 does not contain any physical barriers that prevent vehicles from turning left into the access point but the presence of two yellow solid lines (undivided median treatment) without any breaks does not explicitly allow left turns (although allowed on Indiana road).
3. *Unmarked Pavement:* This type is characterized by an intentional opening in the case of non-traversable medians or lack of yellow line markings or left-turn

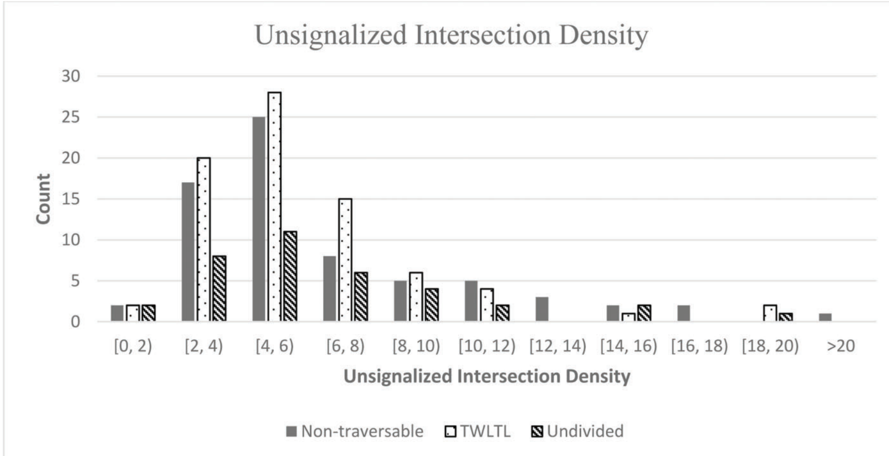


Figure 4.13 Distribution of unsignalized intersection density.

(a) Satellite view (IndianaMap, 2024)

(b) Street View (Google, 2023)

Figure 4.14 Example of a one-directional access point.

restriction signs for undivided median treatments. Driveways on road segments with TWLTL were considered as this type as the additional lane is explicitly provided for this purpose. TWLTLs typically have breaks only when there is an unsignalized intersection leading to a minor street Figure 4.19.

4.2.9 Access Points Exit Marking

The access points exit markings are classified into three types based on the same marking types as described in access point entry marking: continuous median, continuous centerline, and unmarked pavement.

4.2.10 Access Points Density

For a given segment, the number of driveways present between its end points divided by the length of the segments yields *driveway density*. The driveways include all the curb openings on both sides of the analyzed road segment and outside of minor intersections. Similarly, the number of unsignalized intersections within the endpoints of the segment divided by its length yields *unsignalized intersection density*.

4.3 Summary Statistics for Segments

The summary statistics of the variables related to segments are shown in Table 4.2.

As shown in Table 4.3, there is only around 10% of data with either one-directional access points or two-directional access points with island. Therefore, density of access points based on directionality has not been used in the study and are not provided in Table 4.2.

The Highway Safety Manual (HSM) (AASHTO, 2010) classifies driveways into two categories, major and minor. Driveways with fewer than 50 parking spaces or less than 900 vehicles per day are considered minor. Due to time constraints, counting parking spots for over 1,500 driveways in the data were not undertaken. All driveways were treated equally.

4.4 Summary Statistics for Access Points

The software developed by CRS that was used to mark end points of segments was also used to mark locations of access points along the road corridor. In total 3,019 access points (both driveways and unsignalized intersections) were manually tagged and their properties such as directionality, markings on entry or

Figure 4.15 Example of a two-directional access point (IndianaMap, 2024).

Figure 4.16 Example of a two-directional access point with island (IndianaMap, 2024).

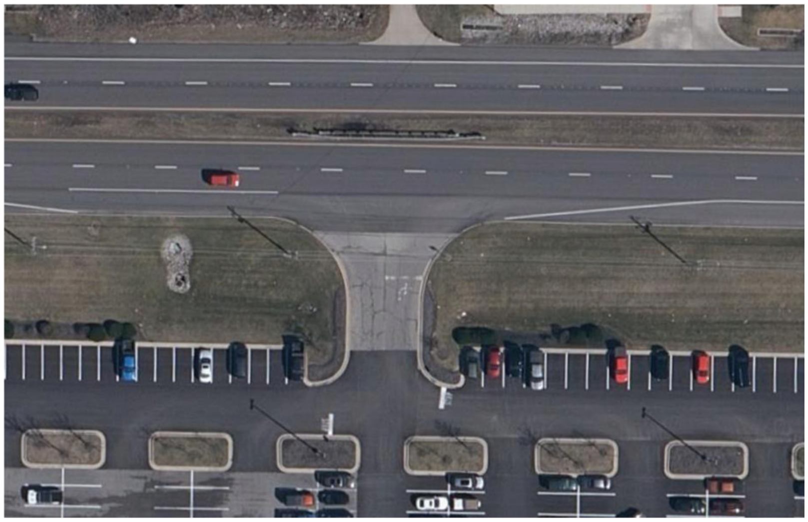


Figure 4.17 Example of an access point with a continuous median (IndianaMap, 2024).

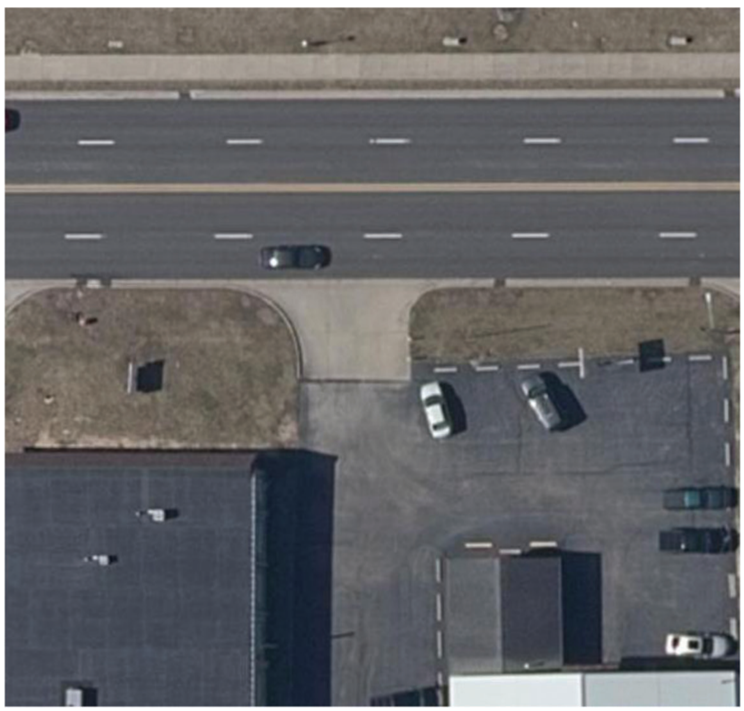


Figure 4.18 Example of an access point with a continuous centerline (IndianaMap, 2024).

exit were recorded. The summary statistics of different variables that are related to access points are shown in Table 4.3.

4.5 Crash Data

Crashes from 2015 to 2022 were obtained from the Automated Reporting Information Exchange System (ARIES) which is an electronically updated database of police-reported crashes occurring in Indiana. Using GIS tools, crashes belonging to the road sections used for this study were extracted. Further each crash was then assigned to a segment or intersection based on proximity. The list of crashes was further processed to remove the following types of crashes.

- *Crashes occurring at parking lots:* These are crashes that occur on parking lots adjacent to the major road under consideration. These crashes are not influenced by median treatment on the major road and thus are removed from analysis.

Figure 4.19 Example of an access point with unmarked pavement (IndianaMap, 2024).

- *Crashes involving animals:* This study focuses on interaction between vehicles and thus crashes involving animals are excluded.

A summary of the number of crashes by severity along segments with different median treatments is given in Table 4.4.

TABLE 4.2
Summary statistics for variables related to segments

Variable	Mean	Median	Standard Deviation	Min	Max
Segment length (miles)	0.27	0.24	0.17	0.03	0.81
Number of through lanes	4.26	4.00	0.98	2.00	6.00
Posted speed limit	42.03	45.00	7.04	30.00	60.00
AADT (2015)	21,404	19,778	9,663	7,826	46,779
AADT (2016)	23,107	22,291	9,139	7,776	46,253
AADT (2017)	23,107	22,200	9,104	4,442	46,253
AADT (2018)	23,154	21,945	9,137	7,364	46,253
AADT (2019)	23,229	22,336	9,223	7,364	47,320
AADT (2020)	20,290	20,366	8,700	3,828	46,253
AADT (2021)	20,373	20,086	9,100	4,073	44,458
Driveway density	30.18	28.26	23.19	0	104.91
Density of driveways with continuous median on entry	6.46	0	12.32	0	61.56
Density of driveways with continuous centerline on entry	20.33	5.21	25.55	0	96.39
Density of driveways with unmarked pavement on entry	3.39	0	6.63	0	39.74
Density of driveways with continuous median on exit	6.29	0	11.82	0	61.56
Density of driveways with continuous centerline on exit	20.23	6.19	25.39	0	96.39
Density of driveways with unmarked pavement exit	3.38	0	6.56	0	39.74
Unsignalized intersection density	5.72	4.49	6.35	0	32.79
Density of unsignalized intersections with continuous median on entry	0.61	0	2.5	0	26.00
Density of unsignalized intersections with continuous centerline on entry	1.70	0	3.21	0	14.44
Density of unsignalized intersections with unmarked pavement on entry	3.40	0	5.58	0	32.79
Density of unsignalized intersections with continuous median on exit	0.70	0	2.67	0	26.00
Density of unsignalized intersections with continuous centerline on exit	1.72	0	3.21	0	14.44
Density of unsignalized intersections with unmarked pavement on exit	3.30	0	5.50	0	32.79

TABLE 4.3
Summary statistics related to access points

Variable	Count	Percent of Observations (%)
Access points directionality	–	–
One directional	71	2.35
Two-directional	2,662	88.18
Two-directional with island	286	9.47
Access point entry marking	–	–
Access points with continuous median on entry	760	25.17
Access points with continuous centerline on entry	1,773	58.73
Access points with unmarked pavement on entry	486	16.1
Access point exit marking	–	–
Access points with continuous median on exit	760	25.17
Access points with continuous centerline on exit	1,778	58.89
Access points with unmarked pavement on exit	481	15.94

TABLE 4.4
Crash statistics

Median Type	Total Miles	No. of Segments	KA Crash	BC Crash	PD Crash	Total Crash Count
Undivided	9.75	33	132	176	921	1,229
TWLTL	22.29	86	277	336	2,263	2,876
Non-traversable	21.76	81	249	325	2,039	2,613
Segments total	53.8	200	658	837	5,223	6,718

5. STATISTICAL ANALYSIS

5.1 Data Descriptive Summary

The data descriptive summary of the variables used in the models are shown in Table 5.1.

5.2 Model Specification

The presented study evaluates the safety performance of state-administered urban and suburban non-freeway arterial roads with three types of cross-sections as described in the Introduction, undivided, with a two-way left-turn lane (TWLTL), and divided with a non-traversable median. For convenient use, the following chapters will use undivided, TWLTL, and non-traversable to represent the three median types.

The analysis was accomplished by estimating the safety effects of these three median treatments on traffic. To achieve this goal, advanced econometric models were developed that connected traffic and geometric characteristics with crash frequency and severity for 200 segments (total length of 54 miles) with diversified median treatments across Indiana. Specifically, the data included the segment length between intersections, the type of median treatments, AADT, the number of road access points with different markings (converted to the density per mile), the number of unsignalized intersections, the speed limit and number of through lanes. Eight years of crash data from 2015 to 2022 were used in the analysis.

The roadway safety performance can be evaluated with crash frequency and crash severity. The corresponding models were developed and included in Appendix A. Although the crash frequency and severity models are intuitive and informative, they are not particularly useful when applied to compare alternative median types. A better method is to use the cost of crashes that can be directly included in the benefit-cost analysis together with the cost of building a new road segment or the cost of converting an existing segment into one with a new median treatment. Therefore, applicable econometric models were proposed, and the following paragraphs introduce the modeling assumptions, resulting models and crash predictions, and their conversion to the cost of crashes.

In the presented study, a homogeneous-median segment with its geometry, traffic and crash is treated as one observation. For each observation, crashes were accumulated by severity over 8 years (2015–2022) to ensure sufficient crash counts for the models' statistical significance. The crash count was initially assumed to be affected by segment length, AADT (mean AADT over the 8 years), number of lanes, speed limit, number of driveways, number of minor (unsignalized) intersections and median treatment type. Among these factors, segment length was treated as the exposure to crashes and a linear connection to number of crashes was assumed. This intuitive and reasonable assumption provided an easy conversion of the expected number of crashes on a segment into its crash density per mile; thus, leading to a convenient generalization of the results.

In the original trials of models, the access points with different markings (continuous median, continuous centerline, unmarked pavement) were introduced into the models separately. However, in most cases, the coefficient difference among these access points with different markings was not found statistically significant and thus they are treated as the same type of access point in the following analysis. To increase the implementation convenience, the safety effect of driveways and unsignalized intersections was combined by replacing an unsignalized intersection with an equivalent number of driveway access points. To establish this equivalency, a statistical safety impact model was estimated multiple times with assumed different intersection/driveway equivalencies until the best performing model was found. The best goodness of fit model was found for the value of five driveways per unsignalized intersection (the estimated goodness of fit model is included in Appendix B). Thus, the generalized access density was calculated for each road segment after minor intersections were converted to the equivalent five access points.

TABLE 5.1
Data descriptive summary

Variable	Description	Mean	Std Dev	Min	Max
Length	Segment length in mile	0.27	0.17	0.03	0.81
SpdLimit	Speed limit in mph	42.1	7.1	30	60
DrWay	Number of driveway access points	8.1	8.9	0	45
UnSig	Number of unsignalized intersections	1.5	1.8	0	9
AcsDen	General access point density per mile	58.7	40.3	0	180.4
LaneNum	Number of lanes	Categorical: 2 or 3 lanes: 7.0%; 4 or 5 lanes: 75%; 6 lanes: 18%			
AADT	Annual average daily traffic	21,397	9,674	7,826	46,779
PD	Property damage crash count	26.1	30.1	0	221
BC	Minor and non-incapacitating injury crash count	4.2	5.9	0	55
KA	Fatal and incapacitating crash count	3.3	4.6	0	27
Med	Median treatments	Categorical: Undivided: 16.5%; TWLTL: 43.0%; Non-traversable: 40.5%			

The general crash count model is expressed with Eq. 5.1, where the speed limit and the generalized access point density are inside the exponential function while the AADT is raised to a certain power. The segment length is an offset variable; it is assumed to have a proportional effect (linear) on the number of crashes on a segment.

$$CrashNum = \text{Length} * (\text{AADT})^{\beta_1} * \exp(\beta_0 + \beta_2 SpdLmt + \beta_3 AcsDen) + \varepsilon \qquad \text{(Eq. 5.1)}$$

Traffic engineers typically set speed limits based on the 85th speed percentile estimated with field measurements and consideration of the road design standard. It has been demonstrated in past research that drivers adjust their speeds to their safety perception including the road geometry, density of access points, and AADT. Therefore, there potentially exists an endogenous relationship between crash density and speed limit (both-way relationship). Safety is affected by speed limits, while speed limits are affected by safety. Not considering this phenomenon when estimating safety may lead to unrealistic and misleading results.

To address this endogeneity problem, simultaneous equations were used as shown in Eq. 5.2 and Eq. 5.3. The two simultaneous equations are estimated together to get the unbiased safety factors. It should be noted that Eq. 5.2 is a mathematical transformation of Eq. 5.1, so the assumptions of the initial crash count model remain the same.

$$\log\left(\frac{CrashNum}{Length}\right) = \beta_0 + \beta_1 \log(\text{AADT}) + \beta_2 SpdLmt + \beta_3 AcsDen + \delta \qquad \text{(Eq. 5.2)}$$

$$SpdLmt = \phi_0 + \phi_1 \log\left(\frac{CrashNum}{Length}\right) + \phi_2 \log(Length) + \phi_3 AcsDen + \in \qquad \text{(Eq. 5.3)}$$

Models in Eq. 5.2 and Eq. 5.3 were estimated for each of the three median treatments considered for their pairwise comparison. The estimated coefficients in these models were used to predict the expected crash density (crash count per mile) for each of the three median treatments (Eq. 5.4).

$$CrashDen = \frac{CrashNum}{Length} = \exp(\beta_0 + \beta_1 \log(\text{AADT}) + \beta_2 SpdLmt + \beta_3 AcsDen) \qquad \text{(Eq. 5.4)}$$

The comprehensive annual cost of crashes for each of the three studied median treatments was calculated by summing up comprehensive costs of crashes at three severity levels: KA (fatal and incapacitating), BC (non-incapacitating and other injury), and PD (property damage only). Thus, three severity level (i = KA, BC, PD) and three median treatments (j = undivided, TWLTL, non-traversable) yielded nine sets of simultaneous equations (Eq. 5.5 and Eq. 5.6) to be estimated:

$$\log\left(\frac{CrashNum_{ij}}{Length}\right) = \beta_{0ij} + \beta_{1ij} \log(\text{AADT}) + \beta_{2ij} SpdLmt + \beta_{3ij} AcsDen + \delta_{ij} \qquad \text{(Eq. 5.5)}$$

$$SpdLmt = \phi_{0ij} + \phi_{1ij} \log\left(\frac{CrashNum_{ij}}{Length}\right) + \phi_{2ij} \log(\text{Length}) + \phi_{3ij} AcsDen + \in_{ij} \qquad \text{(Eq. 5.6)}$$

Then, the expected crash cost per mile for a median treatment j (j = undivided, TWLTL, non-traversable) was obtained with Eq. 5.7 where CostKA, CostBC, and CostPD are summarized average comprehensive crash costs.

$$Expd\ Crash\ Cost\ per\ mile_j = CostKA * \frac{CrashNum_{KAj}}{Length} + CostBC * \frac{CrashNum_{BCj}}{Length} + CostPD * \frac{CrashNum_{PDj}}{Length} \qquad \text{(Eq. 5.7)}$$

5.3 Model Estimation Results

Table 5.2 provides the coefficients of the crash density models from the nine simultaneous equations. Detailed estimation results for each model are included in Appendix C. Although the coefficients for different models in Table 5.2 vary, their signs (positive or

TABLE 5.2
Coefficients of the simultaneous equations (crash) by severity and median treatment

Severity	Median Treatment	Intercept	SpdLmt	Log (AADT)	AcsDen
KA	Undivided	-13.360	-0.013	1.614	0.011
	TWLTL	-4.672	0.007	0.573	0.010
	Non-traversable	1.040	-0.044	0.209	0.011
BC	Undivided	-6.666	-0.077	1.237	0.006
	TWLTL	-4.911	-0.046	0.844	0.007
	Non-traversable	-10.537	-0.069	1.493	0.010
PD	Undivided	-12.615	-0.054	1.928	0.010
	TWLTL	-3.046	-0.016	0.712	0.014
	Non-traversable	0.151	-0.068	0.610	0.015

negative) are largely consistent. The speed limit is expected to have a negative effect on crash frequency. A higher speed limit frequently indicates better roadway operational conditions and potentially less conflicts. The traffic exposure, represented by the logarithm of annual average daily traffic, will increase the probability of crashes as expected. The density of access points is expected to increase crashes since they bring more conflict points. All the three variables included in the crash model show reasonable and expected effects on safety performance.

$$\begin{aligned}&\text{Annual Crash Cost per mile (Undivided)}\\&=0.125*(CostKA*\exp(-13.360\\&-0.013*SpdLmt+1.614*\log(\text{AADT})+0.011\\&*AcsDen)+CostBC\\&*\exp(-6.666-0.077*SpdLmt+1.237\\&*\log(\text{AADT})+0.006*AcsDen)\\&+CostPD*\exp(-12.615-0.054\\&*SpdLmt+1.928*\log(\text{AADT})+0.01\\&*AcsDen))\end{aligned} \quad \text{(Eq. 5.8)}$$

$$\begin{aligned}&\text{Annual Crash Cost per mile (TWLTL)}\\&=0.125*(CostKA*\exp(-4.672\\&+0.007*SpdLmt+0.573*\log(\text{AADT})\\&+0.010*AcsDen)+CostBC\\&*\exp(-4.911-0.046*SpdLmt+0.844\\&*\log(\text{AADT})+0.007*AcsDen)\\&+CostPD*\exp(-3.046-0.016\\&*SpdLmt+0.712*\log(\text{AADT})+0.014\\&*AcsDen))\end{aligned} \quad \text{(Eq. 5.9)}$$

$$\begin{aligned}&Annual\ Crash\ Cost\ per\ mile\ (Non\text{-}traversable)\\&=0.125*(CostKA\\&*\exp(-1.04-0.044*SpdLmt+0.209\\&*\log(\text{AADT})+0.011*AcsDen)\\&+CostBC*\exp(-10.537-0.069\\&*SpdLmt+1.493*\log(\text{AADT})+0.01\\&*AcsDen)+CostPD*\exp(0.151-0.068\\&*SpdLmt+0.61*\log(\text{AADT})\\&+0.015*AcsDen))\end{aligned} \quad \text{(Eq. 5.10)}$$

The model coefficients were used to estimate annual crash cost per mile for the three median treatments using the following equations (Eq. 5.8, Eq. 5.9, and Eq. 5.10), where the cost unit is 1,000 USD (year 2022). The coefficients (CostKA, CostBC, and CostPD) in front of each exponential term are the comprehensive costs of a crash. These costs are summarized in Table 5.3 for different speed limits in miles per hour. They should be updated for future years if needed.

TABLE 5.3
Average comprehensive crash cost (1,000 USD) by severity and speed limit

Speed Limit (mph)	PD	BC	KA
30–35	45.7	335.3	1,658.0
40–45	43.1	332.4	1,896.5
50+	30.2	318.3	2,577.2

Although different coefficients were obtained for different median treatments (Table 5.2), some of them are close to one another. The detailed statistical analysis presented in Appendix A could not confirm in some cases a significant difference between the crash costs of two different median treatments out of the three considered. Nevertheless, in most cases, segments with TWLTL and segments with undivided could be distinguished. On the other hand, there was no sufficient statistical evidence to distinguish segments with non-traversable median from segments with TWLTLs in many cases. The detailed differences among treatments are calculated and compared in the model application chapter.

It must be emphasized though that this lack of significant difference in crash costs applies to consideration of a single segment. The significance of crash cost difference (reduction = benefit) is growing with the number of segments considered for implementation. Thus, the important result is the expected difference between the crash costs compared to the treatment costs.

6. RESULTS IMPLEMENTATION

Selecting the most promising median treatment for a considered segment involves using one or more tables or graphs provided in this report. The required inputs include: the segment speed limit, the density of access points, and the segment AADT. Although speed limit and AADT do not require additional explanations, the way the density of access points is calculated should be consistent with the one implemented in the presented report. All the unsignalized intersections of the arterial road with crossing roads between signalized intersections are counted. Then, all the curb openings on either side of the analyzed road segment and outside of minor intersections are counted. The number of unsignalized intersections multiplied by factor five are added to the number of access points and the obtained total is divided by the arterial segment length expressed in miles. For clarification, the arterial segment length ends at the beginning of an auxiliary lane taper or 250 feet from the center of the downstream interstation—whichever yields a shorter arterial segment.

The research results are presented for implementation in three formats.

(1) *Crash cost tables* with the expected crash costs per mile for three median treatments, access point density (multiples of 10 access points/mile), and AADT (multiples of 2,000 veh/day) (Table 6.1, Table 6.2, Table 6.3, Table 6.4, Table 6.5, and Table 6.6). Road Hazard Analysis Tool (RoadHAT) was used to obtain the expected annual crashes per mile (Appendix D). Then, comprehensive crash costs for each speed limit (Table 5.3) were used in conjunction with the expected annual crashes per mile to obtain the expected annual crash cost per mile (Appendix D). This can be used by practitioners as a reference to compare costs of different median treatments.

(2) *Selection graphs* with named median treatments with the lowest crash costs under conditions defined with speed limit, access point density, and AADT (Figure 6.2, Figure 6.3, Figure 6.4, Figure 6.5, Figure 6.6, and Figure 6.7).

(3) *Alternative selection tables* with labelled median treatments that perform best or close to the best. Crash costs differ in order of magnitude based on severity. Due to inherent randomness in the severity outcome of a single crash event, the cost varies significantly. Therefore, despite a median treatment having the lowest cost, it is considered equivalent to an alternative if the expected crash cost of the alternative is less than a predefined multiple of the lowest cost treatment. This multiple is termed as MCR (maximum cost ratio).

6.1 Crash Cost Tables

The crash cost tables (Table 6.1, Table 6.2, Table 6.3, Table 6.4, Table 6.5, and Table 6.6) help users select the most promising median treatment for a specific speed limit, AADT, and the density of access points. The lowest crash costs across three median treatments for specific conditions (speed limit, AADT, and access point density) are marked with a bold font.

Most of the values in the crash cost tables are model-based estimated costs for conditions that fall inside the observed data range. These estimates are typed in a regular (straight) font. Some other values are extrapolation of the model predictions, and they are outside of the data point ranges observed for specific speed limits. These values are typed in an italic font. The distributions of the observed data for different speed limits and median treatments are provided in Appendix E.

Because there is only non-traversable median type in the observed data when speed limit is 60 mph, the non-traversable median treatment is recommended when the speed limit is above 55 mph.

It is advised that the non-traversable median treatment be implemented on six-lane segments regardless of the traffic and access point density conditions. This advice is justified with the results which indicate more crashes on six-lane arterial roads with a TWLT lane than on six-lane roads with the alternative cross-sections, particularly on non-traversable divided roads (Appendix A).

6.2 Selection Graphs

Among the three key factors of the models, AADT, density of access points and speed limit, speed limit usually changes by every 5 miles, the annual crash cost per mile (Z axis) with respect to AADT (X axis) and access point density (Y axis) are calculated in the 3D space for different speed limits (30 mph, 35 mph, … 55 mph). The values of the annual crash cost per mile from 3D surfaces (Figure 6.1), the altitude of these 3D surfaces represent the expected crash costs for different median treatments. The lowest envelope of the three surfaces represents the lowest crash costs if the optimal median treatment is selected.

Figure 6.1 shows one of the 3D surface examples under 45 mph speed limit. The non-traversable and TWLTL types are very close in terms of crash cost per mile, but as traffic (AADT) grows, the optimal median treatment changes from TWLTL to non-traversable. The Undivided median type performed reasonably when traffic is low, but the estimated crash cost will increase dramatically as AADT grows, which is consistent with median selection guidance. This 3D surface figure is used as an example to illustrate the critical factors and how they affect estimated average crash cost.

The lowest envelope of three surfaces for the three median treatments is projected to the X-Y surface to obtain the ranges labelled with the safest median treatments (Figure 6.2, Figure 6.3, Figure 6.4, Figure 6.5, Figure 6.6, and Figure 6.7). Users could choose the safest median treatment under different traffic, speed limits, and access control levels.

It should be noted that the ranges presented in Figures 6.2 through 6.7 show only the median treatments with the lowest estimated cost. While as identified in Section 6.1, there are many cases when the costs of other alternatives are very close to the lowest cost. For such cases, the alternative median treatments perform equally well and should be considered by traffic engineers as well. These close crash costs among median alternatives are reflected in Section 6.3, where all potentially allowable median treatments are provided.

6.3 Alternative Selection Tables

The presented preferrable median treatments in Section 6.2 included the ones with the lowest estimated crash costs. However, in some conditions, the crash costs among two or three median treatments are sufficiently close to considering another alternative whose cost is not expected significantly different from the best option under the inherent uncertainty present in such analyses. To help engineers identify these cases, this section includes recommended multiple median treatments to select from. The costs of these alternatives, although higher than the winner, are within the acceptable range.

There are three alternatives for each scenario for selecting among the promising alternative median treatments with allowed maximum percentage of the lowest cost (50%, 75%, and 100%); They correspond to the maximum allowable cost ratios: 1.5. 1.75, and 2. These alternatives are provided for speed limits between 30 and 55 mi/h and for a wide range of arterial AADT access point densities. The recommendations in Figures 6.8 through 6.25 have the preferred median treatment (lowest cost) and all other promising median treatments (costs within the maximum percent of the lowest cost).

The order (horizontal or vertical) of the median treatments reflects the order of their safety performance, i.e., the first median type is the one with the lowest crash cost. For instance, in Figure 6.10, the TWLTL has the lowest cost for AADT ranging from 14,000 to 50,000 for access densities up to 100 access points per mile. The second lowest cost for the same criteria is non-traversable. Due to the table space constraints, the median treatments are abbreviated as U, T, and N for undivided, TWLTL and non-traversable, respectively.

6.4 Median Treatment Application Summary

The selection of median treatment depends on various factors, including safety considerations, construction/reconstruction cost, land use and so on. This project focuses on the safety considerations. The model provided estimates the expected crash costs for the three median treatments considered under different conditions.

The previous subchapters show the exact estimated crash costs (Section 6.1), the best median treatment under various conditions (Section 6.2), and the alternative median treatments that performs closely the best one (Section 6.3). These findings are summarized in Table 6.7 and Table 6.8, where the critical conditions are concluded, and traffic engineers could directly use without calculating the safety performance equations.

The conditions in Table 6.7 are those with lowest crash costs, while Table 6.8 shows conditions when MCR (maximum cost ratio) equals 1.5, thereby exist overlaps of conditions. When users want to check the median treatment with the lowest crash costs, they should check Table 6.7 but when they want to consider alternatives, they should check Table 6.8.

TABLE 6.1
Annual comprehensive crash cost (1,000 USD/mile), speed limit = 30 mph

Access Point Density	Median Type	Annual Average Daily Traffic 2,000	4,000	6,000	8,000	10,000	12,000	14,000	16,000	18,000	20,000	22,000	24,000	26,000
10	Undivided	**130**	**360**	650	1,000	1,410	1,860	2,360	2,910	3,490	4,120	4,790	5,490	6,230
	TWLTL	300	460	**600**	**730**	**840**	**950**	**1,050**	**1,150**	**1,240**	**1,340**	**1,420**	**1,510**	**1,590**
	Non-traversable	970	1,180	1,340	1,490	1,620	1,740	1,870	1,980	2,100	2,220	2,340	2,450	2,570
20	Undivided	**140**	**390**	710	1,100	1,540	2,040	2,600	3,190	3,840	4,530	5,270	6,040	6,860
	TWLTL	330	510	**670**	**800**	**930**	**1,050**	**1,160**	**1,270**	**1,370**	**1,470**	**1,570**	**1,660**	**1,750**
	Non-traversable	1,090	1,330	1,510	1,670	1,820	1,960	2,100	2,230	2,360	2,490	2,620	2,750	2,890
30	Undivided	**150**	**420**	780	1,200	1,690	2,240	2,850	3,510	4,220	4,980	5,790	6,650	7,550
	TWLTL	360	560	**730**	**890**	**1,030**	**1,160**	**1,280**	**1,400**	**1,510**	**1,620**	**1,730**	**1,830**	**1,930**
	Non-traversable	1,220	1,490	1,700	1,880	2,050	2,200	2,360	2,510	2,660	2,800	2,950	3,100	3,240
40	Undivided	**170**	**460**	850	1,320	1,860	2,470	3,130	3,860	4,650	5,480	6,380	7,320	8,320
	TWLTL	400	620	**810**	**980**	**1,130**	**1,280**	**1,410**	**1,540**	**1,670**	**1,790**	**1,910**	**2,020**	**2,130**
	Non-traversable	1,370	1,680	1,910	2,110	2,300	2,480	2,650	2,820	2,990	3,150	3,320	3,480	3,650
50	Undivided	**180**	**510**	930	1,450	2,040	2,710	3,450	4,250	5,110	6,040	7,020	8,070	9,160
	TWLTL	440	690	**900**	**1,080**	**1,250**	**1,410**	**1,560**	**1,700**	**1,840**	**1,970**	**2,100**	**2,230**	**2,350**
	Non-traversable	1,540	1,880	2,150	2,380	2,590	2,790	2,980	3,170	3,360	3,550	3,730	3,910	4,100
60	Undivided	**200**	**550**	1,020	1,590	2,240	2,980	3,790	4,670	5,630	6,650	7,740	8,890	10,100
	TWLTL	490	760	**990**	**1,190**	**1,380**	**1,560**	**1,720**	**1,880**	**2,030**	**2,180**	**2,320**	**2,460**	**2,590**
	Non-traversable	1,730	2,120	2,410	2,670	2,910	3,140	3,360	3,570	3,780	3,990	4,200	4,400	4,610
70	Undivided	**220**	**610**	1,120	1,750	2,470	3,280	4,170	5,150	6,200	7,330	8,530	9,800	11,140
	TWLTL	540	840	**1,090**	**1,320**	**1,520**	**1,720**	**1,900**	**2,080**	**2,240**	**2,410**	**2,560**	**2,720**	**2,860**
	Non-traversable	1,940	2,380	2,710	3,010	3,280	3,530	3,780	4,020	4,250	4,490	4,720	4,950	5,190
80	Undivided	**240**	**670**	1,230	1,920	2,710	3,610	4,590	5,670	6,830	8,080	9,410	10,810	12,290
	TWLTL	600	930	**1,210**	**1,460**	**1,690**	**1,900**	**2,100**	**2,300**	**2,480**	**2,660**	**2,830**	**3,000**	**3,170**
	Non-traversable	2,180	2,670	3,050	3,380	3,690	3,980	4,250	4,520	4,790	5,050	5,310	5,570	5,840
90	Undivided	**260**	**730**	1,350	2,110	2,980	3,970	5,060	6,250	7,530	8,910	10,380	11,930	13,560
	TWLTL	660	1,030	**1,340**	**1,610**	**1,860**	**2,100**	**2,320**	**2,540**	**2,740**	**2,940**	**3,130**	**3,320**	**3,500**
	Non-traversable	2,450	3,010	3,440	3,810	4,150	4,480	4,790	5,090	5,390	5,690	5,980	6,280	6,570
100	Undivided	**280**	**800**	1,490	2,320	3,290	4,370	5,580	6,890	8,310	9,830	11,450	13,170	14,970
	TWLTL	730	1,140	**1,480**	**1,780**	**2,060**	**2,330**	**2,570**	**2,810**	**3,030**	**3,250**	**3,460**	**3,670**	**3,870**
	Non-traversable	2,750	3,380	3,870	4,290	4,670	5,040	5,390	5,740	6,070	6,410	6,740	7,070	7,400

Continued

TABLE 6.1
(Continued)

Access Point Density	Median Type	Annual Average Daily Traffic 26,000	28,000	30,000	32,000	34,000	36,000	38,000	40,000	42,000	44,000	46,000	48,000	50,000
10	Undivided	6,230	7,010	7,820	8,670	9,550	10,470	11,420	12,400	13,410	14,460	15,530	16,640	17,780
	TWLTL	**1,590**	**1,670**	**1,750**	**1,830**	**1,910**	**1,980**	**2,060**	**2,130**	**2,200**	**2,270**	**2,340**	**2,410**	**2,480**
	Non-traversable	2,570	2,690	2,800	2,920	3,040	3,160	3,290	3,410	3,530	3,660	3,780	3,910	4,040
20	Undivided	6,860	7,720	8,610	9,550	10,520	11,530	12,580	13,660	14,780	15,940	17,120	18,350	9,600
	TWLTL	**1,750**	**1,840**	**1,930**	**2,020**	**2,100**	**2,180**	**2,260**	**2,340**	**2,420**	**2,500**	**2,580**	**2,650**	**2,730**
	Non-traversable	2,890	3,020	3,150	3,280	3,420	3,550	3,690	3,820	3,960	4,100	4,240	4,390	4,530
30	Undivided	7,550	8,500	9,490	10,520	11,590	12,710	13,870	15,060	16,300	17,570	18,880	20,230	21,620
	TWLTL	**1,930**	**2,030**	**2,130**	**2,220**	**2,310**	**2,410**	**2,490**	**2,580**	**2,670**	**2,750**	**2,840**	**2,920**	**3,000**
	Non-traversable	3,240	3,390	3,540	3,690	3,840	3,990	4,140	4,290	4,450	4,600	4,760	4,920	5,080
40	Undivided	8,320	9,360	10,450	11,590	12,780	14,010	15,290	16,610	17,970	19,380	0,830	22,320	23,860
	TWLTL	**2,130**	**2,240**	**2,350**	**2,450**	**2,550**	**2,650**	**2,750**	**2,850**	**2,940**	**3,040**	**3,130**	**3,220**	**3,310**
	Non-traversable	3,650	3,810	3,980	4,140	4,310	4,480	4,650	4,820	4,990	5,170	5,340	5,520	5,700
50	Undivided	9,160	10,320	11,520	12,780	14,090	15,450	16,860	18,320	19,830	21,390	22,990	4,640	26,330
	TWLTL	**2,350**	**2,470**	**2,590**	**2,700**	**2,810**	**2,920**	**3,030**	**3,140**	**3,240**	**3,350**	**3,450**	**3,550**	**3,650**
	Non-traversable	4,100	4,280	4,470	4,660	4,840	5,030	5,220	5,420	5,610	5,800	6,000	6,200	6,400
60	Undivided	10,100	11,370	12,710	14,100	15,550	17,050	18,610	20,220	21,890	23,610	25,380	7,200	29,080
	TWLTL	**2,590**	**2,730**	**2,850**	**2,980**	**3,100**	**3,230**	**3,340**	**3,460**	**3,580**	**3,690**	**3,800**	**3,910**	**4,020**
	Non-traversable	4,610	4,820	5,030	5,230	5,450	5,660	5,870	6,090	6,300	6,520	6,740	6,960	7,180
70	Undivided	11,140	12,550	14,020	15,560	17,160	18,820	20,540	22,320	24,170	26,070	8,030	30,040	32,120
	TWLTL	**2,860**	**3,010**	**3,150**	**3,290**	**3,430**	**3,560**	**3,690**	**3,820**	**3,950**	**4,070**	**4,200**	**4,320**	**4,440**
	Non-traversable	5,190	5,420	5,650	5,890	6,120	6,360	6,600	6,840	7,080	7,320	7,570	7,820	8,070
80	Undivided	12,290	13,840	15,470	17,170	18,940	20,780	22,680	24,650	26,690	28,790	0,960	3,190	35,490
	TWLTL	**3,170**	**3,330**	**3,480**	**3,630**	**3,790**	**3,930**	**4,080**	**4,220**	**4,360**	**4,500**	**4,640**	**4,770**	**4,900**
	Non-traversable	5,840	6,100	6,360	6,620	6,890	7,150	7,420	7,690	7,960	8,230	8,510	8,780	9,060
90	Undivided	13,560	15,280	17,080	18,960	20,920	22,950	25,060	27,240	29,490	31,820	34,220	6,680	39,220
	TWLTL	**3,500**	**3,680**	**3,850**	**4,020**	**4,180**	**4,350**	**4,510**	**4,660**	**4,820**	**4,970**	**5,120**	**5,270**	**5,420**
	Non-traversable	6,570	6,860	7,160	7,450	7,750	8,040	8,340	8,650	8,950	9,250	9,560	9,870	10,180
100	Undivided	14,970	16,880	18,870	20,940	23,110	25,360	27,690	30,100	32,600	35,170	7,820	40,560	3,360
	TWLTL	**3,870**	**4,070**	**4,260**	**4,440**	**4,630**	**4,810**	**4,980**	**5,160**	**5,330**	**5,500**	**5,660**	**5,830**	**5,990**
	Non-traversable	7,400	7,730	8,050	8,390	8,720	9,050	9,390	9,730	10,060	10,410	10,750	11,100	11,450

Note: All costs in black are estimates based on limited data and should be treated with caution. The median type with the lowest expected crash cost for given AADT and access point density are boldface.

TABLE 6.2
Annual comprehensive crash cost (1,000 USD/mile), speed limit = 35 mph

Access Point Density	Median Type	Annual Average Daily Traffic												
		2,000	**4,000**	**6,000**	**8,000**	**10,000**	**12,000**	**14,000**	**16,000**	**18,000**	**20,000**	**22,000**	**24,000**	**26,000**
10	Undivided	**100**	**290**	**530**	820	1,150	1,530	1,950	2,400	2,890	3,420	3,980	4,570	5,190
	TWLTL	290	450	580	**700**	**810**	**910**	**1,010**	**1,100**	**1,190**	**1,270**	**1,350**	**1,430**	**1,510**
	Non-traversable	770	930	1,050	1,160	1,260	1,350	1,440	1,530	1,620	1,700	1,790	1,870	1,960
20	Undivided	**110**	**310**	**580**	900	1,270	1,690	2,150	2,650	3,190	3,770	4,390	5,040	5,730
	TWLTL	320	500	640	**770**	**890**	**1,000**	**1,110**	**1,210**	**1,310**	**1,400**	**1,490**	**1,580**	**1,660**
	Non-traversable	860	1,040	1,180	1,300	1,410	1,520	1,620	1,720	1,820	1,910	2,010	2,100	2,200
30	Undivided	**120**	**340**	**640**	990	1,400	1,860	2,370	2,920	3,520	4,160	4,840	5,560	6,320
	TWLTL	350	550	710	**850**	**990**	**1,110**	**1,230**	**1,340**	**1,440**	**1,550**	**1,650**	**1,740**	**1,840**
	Non-traversable	960	1,170	1,330	1,470	1,590	1,710	1,820	1,930	2,040	2,150	2,260	2,360	2,470
40	Undivided	**130**	**380**	**700**	1,090	1,540	2,050	2,610	3,220	3,880	4,590	5,340	6,140	6,980
	TWLTL	390	610	780	**940**	**1,090**	**1,220**	**1,350**	**1,480**	**1,590**	**1,710**	**1,820**	**1,920**	**2,030**
	Non-traversable	1,080	1,320	1,490	1,650	1,790	1,920	2,050	2,170	2,290	2,420	2,540	2,660	2,780
50	Undivided	**150**	**410**	**770**	1,200	1,700	2,260	2,880	3,550	4,280	5,070	5,900	6,780	7,710
	TWLTL	430	670	870	**1,040**	**1,200**	**1,350**	**1,490**	**1,630**	**1,760**	**1,890**	**2,010**	**2,120**	**2,240**
	Non-traversable	1,210	1,480	1,680	1,850	2,010	2,160	2,300	2,440	2,580	2,720	2,850	2,990	3,120
60	Undivided	**160**	**450**	**840**	1,320	1,870	2,490	3,170	3,920	4,730	5,590	6,520	7,490	8,520
	TWLTL	480	740	960	**1,150**	**1,330**	**1,500**	**1,650**	**1,800**	**1,940**	**2,080**	**2,220**	**2,350**	**2,470**
	Non-traversable	1,360	1,660	1,890	2,080	2,260	2,430	2,590	2,750	2,900	3,050	3,210	3,360	3,510
70	Undivided	**180**	**500**	**930**	1,450	2,060	2,740	3,500	4,330	5,220	6,180	7,200	8,280	9,420
	TWLTL	530	820	1,060	**1,270**	**1,470**	**1,650**	**1,830**	**1,990**	**2,150**	**2,300**	**2,450**	**2,590**	**2,730**
	Non-traversable	1,530	1,870	2,120	2,340	2,540	2,730	2,910	3,090	3,260	3,440	3,610	3,780	3,950
80	Undivided	**190**	**550**	**1,020**	1,600	2,270	3,030	3,870	4,780	5,770	6,830	7,960	9,160	10,420
	TWLTL	590	910	1,170	**1,410**	**1,630**	**1,830**	**2,020**	**2,200**	**2,380**	**2,550**	**2,710**	**2,870**	**3,020**
	Non-traversable	1,720	2,100	2,380	2,630	2,860	3,070	3,280	3,480	3,670	3,870	4,060	4,250	4,440
90	Undivided	**210**	**600**	**1,130**	1,770	2,510	3,340	4,270	5,280	6,380	7,550	8,800	10,130	11,520
	TWLTL	650	1,000	1,300	**1,560**	**1,800**	**2,020**	**2,240**	**2,440**	**2,630**	**2,820**	**3,000**	**3,170**	**3,340**
	Non-traversable	1,930	2,360	2,680	2,960	3,220	3,460	3,690	3,910	4,130	4,350	4,570	4,780	4,990
100	Undivided	**230**	**660**	**1,240**	1,950	2,770	3,690	4,720	5,840	7,050	8,350	9,740	11,200	12,750
	TWLTL	720	1,110	1,440	**1,730**	**1,990**	**2,240**	**2,480**	**2,700**	**2,910**	**3,120**	**3,320**	**3,510**	**3,700**
	Non-traversable	2,170	2,650	3,010	3,330	3,620	3,890	4,150	4,410	4,650	4,900	5,140	5,380	5,620

Continued

TABLE 6.2
(Continued)

Access Point Density	Median Type	Annual Average Daily Traffic 26,000	28,000	30,000	32,000	34,000	36,000	38,000	40,000	42,000	44,000	46,000	48,000	50,000
10	Undivided	5,840	6,530	7,240	7,980	8,750	9,550	10,370	11,220	12,100	13,010	13,940	14,900	5,840
	TWLTL	**1,590**	**1,660**	**1,730**	**1,800**	**1,870**	**1,940**	**2,010**	**2,070**	**2,140**	**2,200**	**2,270**	**2,330**	**1,590**
	Non-traversable	2,040	2,130	2,220	2,300	2,390	2,480	2,570	2,660	2,750	2,840	2,930	3,020	2,040
20	Undivided	6,450	7,200	7,990	8,810	9,660	10,540	11,460	12,400	13,370	14,370	15,400	16,460	6,450
	TWLTL	**1,750**	**1,830**	**1,910**	**1,990**	**2,060**	**2,140**	**2,210**	**2,290**	**2,360**	**2,430**	**2,500**	**2,570**	**1,750**
	Non-traversable	2,300	2,390	2,490	2,590	2,680	2,780	2,880	2,980	3,080	3,180	3,290	3,390	2,300
30	Undivided	7,120	7,950	8,820	9,730	10,670	11,650	12,660	13,700	14,780	15,890	17,030	18,200	7,120
	TWLTL	**1,930**	**2,020**	**2,110**	**2,190**	**2,280**	**2,360**	**2,440**	**2,520**	**2,600**	**2,680**	**2,750**	**2,830**	**1,930**
	Non-traversable	2,580	2,690	2,790	2,900	3,010	3,120	3,230	3,350	3,460	3,570	3,690	3,800	2,580
40	Undivided	7,860	8,790	9,750	10,750	11,790	12,870	13,990	15,150	16,340	17,570	18,830	20,130	7,860
	TWLTL	**2,130**	**2,230**	**2,320**	**2,420**	**2,510**	**2,600**	**2,690**	**2,780**	**2,870**	**2,950**	**3,040**	**3,120**	**2,130**
	Non-traversable	2,900	3,020	3,140	3,260	3,380	3,510	3,630	3,750	3,880	4,010	4,140	4,260	2,900
50	Undivided	8,690	9,710	10,770	11,890	13,040	14,230	15,470	16,750	18,070	19,430	20,830	22,260	8,690
	TWLTL	**2,350**	**2,460**	**2,570**	**2,670**	**2,770**	**2,870**	**2,970**	**3,070**	**3,170**	**3,260**	**3,350**	**3,450**	**2,350**
	Non-traversable	3,260	3,390	3,530	3,660	3,800	3,940	4,080	4,220	4,360	4,500	4,640	4,790	3,260
60	Undivided	9,600	10,730	11,910	13,140	14,420	15,740	17,110	18,530	19,990	21,500	23,040	24,640	9,600
	TWLTL	**2,600**	**2,720**	**2,830**	**2,950**	**3,060**	**3,170**	**3,280**	**3,390**	**3,500**	**3,600**	**3,700**	**3,800**	**2,600**
	Non-traversable	3,660	3,810	3,960	4,120	4,270	4,420	4,580	4,740	4,890	5,050	5,210	5,370	3,660
70	Undivided	10,620	11,870	13,180	14,540	15,950	17,420	18,940	20,500	22,120	23,790	25,510	27,270	10,620
	TWLTL	**2,870**	**3,000**	**3,130**	**3,260**	**3,380**	**3,510**	**3,630**	**3,750**	**3,860**	**3,980**	**4,090**	**4,200**	**2,870**
	Non-traversable	4,120	4,280	4,460	4,630	4,800	4,970	5,140	5,320	5,500	5,670	5,850	6,030	4,120
80	Undivided	11,740	13,130	14,580	16,080	17,650	19,280	20,960	22,700	24,490	26,340	28,240	30,190	11,740
	TWLTL	**3,170**	**3,320**	**3,460**	**3,600**	**3,740**	**3,880**	**4,010**	**4,140**	**4,270**	**4,400**	**4,520**	**4,650**	**3,170**
	Non-traversable	4,630	4,820	5,010	5,200	5,390	5,590	5,780	5,980	6,180	6,370	6,570	6,770	4,630
90	Undivided	12,990	14,530	16,130	17,800	19,540	21,340	23,200	25,130	27,120	29,160	31,270	33,440	12,990
	TWLTL	**3,510**	**3,670**	**3,830**	**3,990**	**4,140**	**4,290**	**4,430**	**4,580**	**4,720**	**4,860**	**5,000**	**5,140**	**3,510**
	Non-traversable	5,210	5,420	5,630	5,850	6,070	6,280	6,500	6,720	6,940	7,160	7,390	7,610	5,210
100	Undivided	14,380	16,080	17,860	19,710	21,630	23,630	25,700	27,830	30,030	32,310	34,640	37,050	14,380
	TWLTL	**3,880**	**4,060**	**4,240**	**4,410**	**4,580**	**4,740**	**4,910**	**5,070**	**5,220**	**5,380**	**5,530**	**5,680**	**3,880**
	Non-traversable	5,860	6,100	6,340	6,580	6,820	7,070	7,310	7,560	7,800	8,050	8,300	8,550	5,860

Note: All costs in black are estimates based on limited data and should be treated with caution. The median type with the lowest expected crash cost for given AADT and access point density are boldface.

TABLE 6.3
Annual comprehensive crash cost (1,000 USD/mile), speed limit = 40 mph

Access Point Density	Median Type	Annual Average Daily Traffic												
		2,000	**4,000**	**6,000**	**8,000**	**10,000**	**12,000**	**14,000**	**16,000**	**18,000**	**20,000**	**22,000**	**24,000**	**26,000**
10	Undivided	**90**	**250**	**470**	**740**	1,050	1,390	1,780	2,190	2,650	3,130	3,640	4,190	4,760
	TWLTL	310	480	620	**740**	**850**	**960**	**1,060**	**1,150**	**1,240**	**1,330**	**1,410**	**1,490**	**1,570**
	Non-traversable	680	820	920	1,010	1,080	1,160	1,230	1,290	1,360	1,420	1,490	1,550	1,620
20	Undivided	**100**	**280**	**520**	**810**	1,160	1,540	1,960	2,430	2,930	3,460	4,030	4,630	5,270
	TWLTL	350	530	680	820	**940**	**1,060**	**1,170**	**1,270**	**1,370**	**1,460**	**1,550**	**1,640**	**1,730**
	Non-traversable	760	920	1,030	1,130	1,220	1,300	1,380	1,450	1,530	1,600	1,670	1,740	1,810
30	Undivided	**110**	**310**	**570**	**900**	1,280	1,700	2,170	2,680	3,240	3,830	4,460	5,130	5,840
	TWLTL	380	590	760	910	**1,040**	**1,170**	**1,290**	**1,400**	**1,510**	**1,620**	**1,720**	**1,810**	**1,910**
	Non-traversable	860	1,030	1,160	1,270	1,370	1,460	1,540	1,630	1,710	1,790	1,870	1,950	2,030
40	Undivided	**120**	**340**	**630**	**990**	1,410	1,880	2,400	2,970	3,590	4,240	4,940	5,690	6,470
	TWLTL	420	650	840	1,000	**1,150**	**1,290**	**1,420**	**1,550**	**1,670**	**1,780**	**1,900**	**2,000**	**2,110**
	Non-traversable	960	1,160	1,300	1,420	1,530	1,640	1,730	1,830	1,920	2,010	2,100	2,190	2,280
50	Undivided	**130**	**370**	**700**	**1,100**	1,560	2,080	2,660	3,290	3,970	4,700	5,480	6,300	7,170
	TWLTL	470	720	920	1,110	**1,270**	**1,430**	**1,570**	**1,710**	**1,840**	**1,970**	**2,090**	**2,210**	**2,330**
	Non-traversable	1,080	1,300	1,460	1,600	1,720	1,840	1,950	2,050	2,160	2,260	2,360	2,460	2,560
60	Undivided	**140**	**410**	**770**	**1,210**	1,730	2,310	2,950	3,640	4,400	5,210	6,070	6,980	7,950
	TWLTL	520	790	1,020	1,220	**1,410**	**1,580**	**1,740**	**1,890**	**2,040**	**2,180**	**2,310**	**2,450**	**2,570**
	Non-traversable	1,210	1,450	1,640	1,790	1,930	2,060	2,190	2,310	2,430	2,540	2,650	2,770	2,880
70	Undivided	**160**	**450**	**860**	**1,340**	1,910	2,550	3,260	4,040	4,880	5,780	6,730	7,750	8,810
	TWLTL	570	880	1,130	1,350	**1,560**	**1,740**	**1,920**	**2,090**	**2,250**	**2,410**	**2,560**	**2,700**	**2,850**
	Non-traversable	1,360	1,630	1,840	2,010	2,170	2,320	2,460	2,590	2,720	2,850	2,980	3,110	3,240
80	Undivided	**170**	**500**	**950**	**1,490**	2,120	2,830	3,620	4,480	5,410	6,400	7,470	8,590	9,780
	TWLTL	630	970	1,250	1,500	**1,720**	**1,930**	**2,130**	**2,310**	**2,490**	**2,660**	**2,830**	**2,990**	**3,150**
	Non-traversable	1,520	1,830	2,060	2,260	2,440	2,600	2,760	2,910	3,060	3,210	3,350	3,490	3,630
90	Undivided	**190**	**550**	**1,050**	**1,650**	2,340	3,130	4,010	4,960	6,000	7,100	8,280	9,530	10,850
	TWLTL	700	1,080	1,380	1,660	**1,900**	**2,130**	**2,350**	**2,560**	**2,760**	**2,950**	**3,130**	**3,310**	**3,480**
	Non-traversable	1,700	2,060	2,320	2,540	2,740	2,930	3,100	3,270	3,440	3,610	3,770	3,930	4,080
100	Undivided	**210**	**610**	**1,160**	**1,820**	2,600	3,470	4,440	5,500	6,650	7,880	9,190	10,580	12,040
	TWLTL	780	1,190	1,530	1,830	**2,110**	**2,360**	**2,600**	**2,830**	**3,050**	**3,260**	**3,460**	**3,660**	**3,850**
	Non-traversable	1,910	2,310	2,600	2,850	3,080	3,290	3,490	3,680	3,870	4,050	4,230	4,410	4,590

Continued

TABLE 6.3
(Continued)

Access Point Density	Median Type	Annual Average Daily Traffic 26,000	28,000	30,000	32,000	34,000	36,000	38,000	40,000	42,000	44,000	46,000	48,000	50,000
10	Undivided	4,760	5,360	5,990	6,650	7,330	8,040	8,770	9,530	10,320	11,130	11,960	12,820	13,700
	TWLTL	**1,570**	**1,640**	**1,720**	**1,790**	**1,860**	**1,930**	**2,000**	**2,070**	**2,130**	**2,200**	**2,260**	**2,330**	**2,390**
	Non-traversable	1,620	1,680	1,740	1,810	1,870	**1,930**	**2,000**	**2,060**	**2,130**	**2,200**	**2,260**	**2,330**	**2,400**
20	Undivided	5,270	5,940	6,630	7,360	8,120	8,910	9,720	10,560	11,430	12,330	13,260	14,210	15,180
	TWLTL	**1,730**	**1,810**	**1,900**	**1,980**	**2,050**	**2,130**	**2,210**	**2,280**	**2,350**	**2,430**	**2,500**	**2,570**	**2,630**
	Non-traversable	1,810	1,880	1,960	2,030	2,100	2,170	2,240	2,310	2,390	2,460	2,540	2,610	2,680
30	Undivided	5,840	6,580	7,350	8,160	9,000	9,870	10,770	11,710	12,670	13,670	14,700	15,750	16,840
	TWLTL	**1,910**	**2,000**	**2,090**	**2,180**	**2,270**	**2,350**	**2,440**	**2,520**	**2,600**	**2,680**	**2,750**	**2,830**	**2,910**
	Non-traversable	2,030	2,110	2,190	2,270	2,350	2,430	2,510	2,600	2,680	2,760	2,840	2,930	3,010
40	Undivided	6,470	7,290	8,150	9,040	9,970	10,940	11,950	12,980	14,050	15,160	16,300	17,470	18,670
	TWLTL	**2,110**	**2,210**	**2,310**	**2,410**	**2,500**	**2,600**	**2,690**	**2,780**	**2,870**	**2,950**	**3,040**	**3,120**	**3,210**
	Non-traversable	2,280	2,370	2,460	2,550	2,640	2,730	2,820	2,910	3,000	3,100	3,190	3,280	3,370
50	Undivided	7,170	8,080	9,030	10,030	11,060	12,130	13,250	14,400	15,590	16,820	18,080	19,380	20,720
	TWLTL	**2,330**	**2,440**	**2,550**	**2,660**	**2,760**	**2,870**	**2,970**	**3,070**	**3,170**	**3,260**	**3,360**	**3,450**	**3,540**
	Non-traversable	2,560	2,660	2,760	2,860	2,960	3,070	3,170	3,270	3,370	3,470	3,580	3,680	3,780
60	Undivided	7,950	8,960	10,010	11,120	12,270	13,460	14,700	15,970	17,300	18,660	20,060	21,510	22,990
	TWLTL	**2,570**	**2,700**	**2,820**	**2,940**	**3,050**	**3,170**	**3,280**	**3,390**	**3,500**	**3,600**	**3,710**	**3,810**	**3,910**
	Non-traversable	2,880	2,990	3,100	3,220	3,330	3,440	3,550	3,670	3,780	3,900	4,010	4,130	4,240
70	Undivided	8,810	9,930	11,110	12,330	13,610	14,930	16,310	17,730	19,190	20,710	22,270	23,870	25,520
	TWLTL	**2,850**	**2,980**	**3,120**	**3,250**	**3,380**	**3,500**	**3,630**	**3,750**	**3,870**	**3,980**	**4,100**	**4,210**	**4,320**
	Non-traversable	3,240	3,360	3,490	3,610	3,740	3,860	3,990	4,120	4,240	4,370	4,500	4,630	4,760
80	Undivided	9,780	11,020	12,330	13,690	15,100	16,570	18,100	19,680	21,310	22,990	24,720	26,500	28,330
	TWLTL	**3,150**	**3,300**	**3,450**	**3,590**	**3,730**	**3,870**	**4,010**	**4,140**	**4,270**	**4,400**	**4,530**	**4,660**	**4,780**
	Non-traversable	3,630	3,780	3,920	4,060	4,200	4,340	4,480	4,620	4,770	4,910	5,050	5,200	5,340
90	Undivided	10,850	12,230	13,680	15,190	16,760	18,400	20,090	21,840	23,650	25,520	27,450	29,430	31,460
	TWLTL	**3,480**	**3,650**	**3,810**	**3,970**	**4,130**	**4,280**	**4,430**	**4,580**	**4,730**	**4,870**	**5,010**	**5,150**	**5,290**
	Non-traversable	4,080	4,240	4,400	4,560	4,720	4,870	5,030	5,190	5,350	5,510	5,670	5,830	6,000
100	Undivided	12,040	13,580	15,190	16,860	18,610	20,430	22,310	24,260	26,270	28,350	30,480	32,680	34,940
	TWLTL	**3,850**	**4,040**	**4,220**	**4,400**	**4,570**	**4,740**	**4,910**	**5,070**	**5,230**	**5,390**	**5,550**	**5,700**	**5,850**
	Non-traversable	4,590	4,770	4,950	5,120	5,300	5,480	5,650	5,830	6,010	6,190	6,370	6,550	6,730

Note: All costs in black are estimates based on limited data and should be treated with caution. The median type with the lowest expected crash cost for given AADT and access point density are boldface.

TABLE 6.4
Annual comprehensive crash cost (1,000 USD/mile), speed limit = 45 mph

Access Point Density	Median Type	Annual Average Daily Traffic 2,000	4,000	6,000	8,000	10,000	12,000	14,000	16,000	18,000	20,000	22,000	24,000	26,000
10	Undivided	**70**	**210**	**400**	**630**	900	1,200	1,540	1,900	2,290	2,710	3,160	3,640	4,140
	TWLTL	310	480	610	730	**840**	940	1,040	1,130	1,210	1,300	1,380	1,450	1,530
	Non-traversable	540	650	730	790	850	**900**	**960**	**1,010**	**1,060**	**1,100**	**1,150**	**1,200**	**1,250**
20	Undivided	**80**	**240**	**450**	700	1,000	1,330	1,700	2,110	2,540	3,010	3,510	4,040	4,590
	TWLTL	350	530	680	**810**	**930**	1,040	1,150	1,250	1,340	1,430	1,520	1,610	1,690
	Non-traversable	610	730	810	890	950	**1,010**	**1,070**	**1,130**	**1,180**	**1,240**	**1,290**	**1,340**	**1,400**
30	Undivided	**90**	**260**	**490**	**780**	1,100	1,480	1,890	2,340	2,820	3,340	3,890	4,480	5,100
	TWLTL	380	580	750	890	**1,030**	1,150	1,270	1,380	1,480	1,580	1,680	1,770	1,870
	Non-traversable	680	810	910	1,000	1,070	**1,140**	**1,200**	**1,270**	**1,330**	**1,390**	**1,450**	**1,510**	**1,570**
40	Undivided	**100**	**290**	**550**	**860**	1,220	1,640	2,090	2,590	3,130	3,710	4,320	4,970	5,660
	TWLTL	420	640	830	990	**1,130**	**1,270**	1,400	1,520	1,640	1,750	1,860	1,960	2,060
	Non-traversable	760	910	1,020	1,120	1,200	1,280	**1,350**	**1,420**	**1,490**	**1,560**	**1,630**	**1,690**	**1,760**
50	Undivided	**110**	**320**	**600**	**950**	1,360	1,810	2,320	2,870	3,470	4,110	4,800	5,520	6,280
	TWLTL	470	710	910	1,090	**1,250**	**1,400**	1,550	1,680	1,810	1,930	2,050	2,170	2,280
	Non-traversable	850	1,020	1,150	1,250	1,350	1,430	**1,520**	**1,600**	**1,680**	**1,750**	**1,830**	**1,900**	**1,970**
60	Undivided	**120**	**350**	**670**	**1,060**	1,500	2,010	2,580	3,190	3,850	4,570	5,330	6,130	6,980
	TWLTL	520	790	1,010	1,210	**1,390**	**1,550**	1,710	1,860	2,000	2,140	2,270	2,400	2,520
	Non-traversable	960	1,150	1,290	1,410	1,510	1,610	**1,700**	**1,790**	**1,880**	**1,970**	**2,050**	**2,130**	**2,220**
70	Undivided	**130**	**390**	**740**	**1,170**	1,670	2,230	2,860	3,540	4,280	5,070	5,910	6,810	7,750
	TWLTL	570	870	1,120	1,340	**1,530**	**1,720**	**1,890**	2,060	2,210	2,360	2,510	2,650	2,790
	Non-traversable	1,070	1,290	1,450	1,580	1,700	1,810	1,910	**2,010**	**2,110**	**2,210**	**2,300**	**2,400**	**2,490**
80	Undivided	**150**	**430**	**820**	**1,300**	1,850	2,480	3,170	3,930	4,750	5,630	6,570	7,560	8,610
	TWLTL	630	970	1,240	1,480	**1,700**	**1,900**	**2,090**	2,270	2,450	2,610	2,780	2,930	3,080
	Non-traversable	1,200	1,450	1,620	1,770	1,910	2,030	2,150	**2,260**	**2,370**	**2,480**	**2,590**	**2,690**	**2,800**
90	Undivided	**160**	**480**	**910**	**1,440**	2,060	2,750	3,520	4,370	5,280	6,260	7,300	8,410	9,570
	TWLTL	700	1,070	1,370	1,640	**1,880**	**2,100**	**2,320**	**2,520**	2,710	2,890	3,070	3,240	3,410
	Non-traversable	1,350	1,620	1,820	1,990	2,140	2,280	2,410	2,540	**2,670**	**2,790**	**2,910**	**3,020**	**3,140**
100	Undivided	**180**	**530**	**1,010**	**1,600**	2,280	3,060	3,910	4,850	5,870	6,960	8,120	9,340	10,640
	TWLTL	770	1,180	1,520	1,810	**2,080**	**2,330**	**2,560**	**2,790**	**3,000**	3,200	3,400	3,590	3,780
	Non-traversable	1,510	1,820	2,050	2,240	2,410	2,560	2,710	2,860	**3,000**	**3,130**	**3,270**	**3,400**	**3,530**

Continued

TABLE 6.4
(Continued)

Access Point Density	Median Type	Annual Average Daily Traffic												
		26,000	**28,000**	**30,000**	**32,000**	**34,000**	**36,000**	**38,000**	**40,000**	**42,000**	**44,000**	**46,000**	**48,000**	**50,000**
10	Undivided	4,140	4,660	5,210	5,790	6,380	7,000	7,640	8,310	8,990	9,700	10,430	11,180	11,940
	TWLTL	1,530	1,600	1,670	1,740	1,810	1,880	1,940	2,010	2,070	2,130	2,200	2,260	2,310
	Non-traversable	**1,250**	**1,290**	**1,340**	**1,390**	**1,430**	**1,480**	**1,530**	**1,570**	**1,620**	**1,670**	**1,720**	**1,770**	**1,810**
20	Undivided	4,590	5,170	5,780	6,420	7,080	7,770	8,480	9,220	9,980	10,770	11,580	12,410	13,260
	TWLTL	1,690	1,770	1,850	1,930	2,000	2,070	2,150	2,220	2,290	2,360	2,420	2,490	2,550
	Non-traversable	**1,400**	**1,450**	**1,500**	**1,550**	**1,610**	**1,660**	**1,710**	**1,760**	**1,820**	**1,870**	**1,920**	**1,980**	**2,030**
30	Undivided	5,100	5,740	6,420	7,130	7,860	8,630	9,420	10,240	11,090	11,960	12,860	13,780	14,730
	TWLTL	1,870	1,950	2,040	2,130	2,210	2,290	2,370	2,450	2,530	2,600	2,680	2,750	2,820
	Non-traversable	**1,570**	**1,630**	**1,680**	**1,740**	**1,800**	**1,860**	**1,920**	**1,980**	**2,040**	**2,100**	**2,160**	**2,220**	**2,280**
40	Undivided	5,660	6,380	7,130	7,920	8,730	9,580	10,460	11,370	12,320	13,290	14,280	15,310	16,370
	TWLTL	2,060	2,160	2,260	2,350	2,440	2,530	2,620	2,700	2,790	2,870	2,960	3,040	3,120
	Non-traversable	**1,760**	**1,820**	**1,890**	**1,960**	**2,020**	**2,090**	**2,150**	**2,220**	**2,280**	**2,350**	**2,420**	**2,490**	**2,550**
50	Undivided	6,280	7,080	7,920	8,790	9,700	10,650	11,620	12,640	13,680	14,760	15,870	17,010	18,190
	TWLTL	2,280	2,390	2,490	2,600	2,700	2,800	2,890	2,990	3,080	3,170	3,270	3,350	3,440
	Non-traversable	**1,970**	**2,050**	**2,120**	**2,190**	**2,270**	**2,340**	**2,410**	**2,490**	**2,560**	**2,640**	**2,710**	**2,790**	**2,860**
60	Undivided	6,980	7,870	8,800	9,770	10,780	11,830	12,920	14,040	15,200	16,400	17,640	18,910	20,210
	TWLTL	2,520	2,640	2,760	2,870	2,980	3,090	3,200	3,300	3,410	3,510	3,610	3,710	3,810
	Non-traversable	**2,220**	**2,300**	**2,380**	**2,460**	**2,550**	**2,630**	**2,710**	**2,790**	**2,880**	**2,960**	**3,040**	**3,130**	**3,210**
70	Undivided	7,750	8,740	9,770	10,850	11,980	13,140	14,350	15,610	16,900	18,230	19,610	21,020	22,470
	TWLTL	2,790	2,920	3,050	3,170	3,300	3,420	3,540	3,650	3,770	3,880	3,990	4,100	4,210
	Non-traversable	**2,490**	**2,580**	**2,670**	**2,770**	**2,860**	**2,950**	**3,040**	**3,130**	**3,230**	**3,320**	**3,410**	**3,510**	**3,600**
80	Undivided	8,610	9,710	10,860	12,060	13,310	14,610	15,960	17,350	18,790	20,270	21,800	23,370	24,980
	TWLTL	3,080	3,230	3,370	3,510	3,650	3,780	3,910	4,040	4,170	4,290	4,420	4,540	4,650
	Non-traversable	**2,800**	**2,900**	**3,000**	**3,110**	**3,210**	**3,310**	**3,410**	**3,520**	**3,620**	**3,730**	**3,830**	**3,940**	**4,040**
90	Undivided	9,570	10,790	12,070	13,410	14,800	16,240	17,740	19,290	20,890	22,540	24,240	25,990	27,780
	TWLTL	3,410	3,570	3,730	3,890	4,040	4,190	4,330	4,470	4,610	4,750	4,890	5,020	5,150
	Non-traversable	**3,140**	**3,260**	**3,370**	**3,490**	**3,600**	**3,720**	**3,830**	**3,950**	**4,070**	**4,180**	**4,300**	**4,420**	**4,540**
100	Undivided	10,640	12,000	13,420	14,910	16,460	18,060	19,730	21,450	23,230	25,070	26,960	28,910	30,900
	TWLTL	3,780	3,960	4,130	4,300	4,470	4,630	4,790	4,950	5,110	5,260	5,410	5,560	5,700
	Non-traversable	**3,530**	**3,660**	**3,790**	**3,920**	**4,050**	**4,180**	**4,310**	**4,440**	**4,570**	**4,700**	**4,830**	**4,960**	**5,090**

Note: All costs in black are estimates based on limited data and should be treated with caution. The median type with the lowest expected crash cost for given AADT and access point density are boldface.

TABLE 6.5
Annual comprehensive crash cost (1,000 USD/mile), speed limit = 50 mph

Access Point Density	Median Type	Annual Average Daily Traffic 2,000	4,000	6,000	8,000	10,000	12,000	14,000	16,000	18,000	20,000	22,000	24,000	26,000
10	Undivided	**80**	**230**	**440**	**690**	980	1,310	1,680	2,080	2,510	2,970	3,460	3,980	4,530
	TWLTL	400	600	770	910	1,040	1,160	1,280	1,380	1,480	1,580	1,680	1,770	1,860
	Non-traversable	570	670	740	800	**850**	**890**	**940**	**980**	**1,020**	**1,060**	**1,090**	**1,130**	**1,170**
20	Undivided	**90**	**260**	**490**	**770**	1,090	1,460	1,870	2,310	2,790	3,310	3,860	4,430	5,040
	TWLTL	440	660	850	1,010	1,150	1,280	1,410	1,530	1,640	1,750	1,850	1,950	2,050
	Non-traversable	630	750	830	890	**950**	**1,000**	**1,050**	**1,100**	**1,140**	**1,180**	**1,220**	**1,270**	**1,310**
30	Undivided	**100**	**280**	**540**	**850**	1,220	1,630	2,080	2,580	3,110	3,680	4,290	4,940	5,620
	TWLTL	490	730	930	1,110	1,270	1,420	1,550	1,680	1,810	1,930	2,040	2,150	2,260
	Non-traversable	710	840	930	1,000	**1,060**	**1,120**	**1,180**	**1,230**	**1,280**	**1,320**	**1,370**	**1,420**	**1,460**
40	Undivided	**110**	**320**	**600**	**950**	1,350	1,810	2,320	2,870	3,460	4,100	4,780	5,500	6,260
	TWLTL	540	810	1,030	1,230	1,400	1,560	1,720	1,860	2,000	2,130	2,250	2,380	2,490
	Non-traversable	790	940	1,040	1,120	**1,190**	**1,260**	**1,320**	**1,370**	**1,430**	**1,480**	**1,540**	**1,590**	**1,640**
50	Undivided	**120**	**350**	**670**	**1,060**	1,510	2,020	2,580	3,190	3,860	4,570	5,330	6,130	6,970
	TWLTL	590	890	1,140	1,350	1,550	1,730	1,890	2,050	2,200	2,350	2,490	2,620	2,750
	Non-traversable	890	1,050	1,160	1,250	**1,330**	**1,410**	**1,480**	**1,540**	**1,600**	**1,660**	**1,720**	**1,780**	**1,830**
60	Undivided	**130**	**390**	**740**	**1,170**	1,680	2,240	2,870	3,560	4,300	5,090	5,940	6,830	7,770
	TWLTL	650	990	1,260	1,490	1,710	1,910	2,090	2,270	2,430	2,590	2,750	2,900	3,040
	Non-traversable	1,000	1,170	1,300	1,400	**1,490**	**1,580**	**1,650**	**1,730**	**1,790**	**1,860**	**1,930**	**1,990**	**2,060**
70	Undivided	**150**	**430**	**830**	**1,310**	1,870	2,500	3,200	3,960	4,790	5,670	6,610	7,610	8,660
	TWLTL	720	1,090	1,390	1,650	1,890	2,100	2,310	2,500	2,690	2,860	3,030	3,200	3,360
	Non-traversable	1,110	1,310	1,460	1,570	**1,670**	**1,770**	**1,850**	**1,930**	**2,010**	**2,090**	**2,160**	**2,230**	**2,300**
80	Undivided	**160**	**480**	**920**	**1,450**	2,080	2,780	3,560	4,420	5,340	6,320	7,370	8,480	9,650
	TWLTL	800	1,210	1,530	1,820	2,080	2,330	2,550	2,760	2,970	3,160	3,350	3,530	3,710
	Non-traversable	1,250	1,470	1,630	1,760	**1,880**	**1,980**	**2,070**	**2,170**	**2,250**	**2,340**	**2,420**	**2,500**	**2,580**
90	Undivided	**180**	**540**	**1,020**	**1,620**	2,320	3,100	3,970	4,920	5,950	7,050	8,220	9,450	10,760
	TWLTL	880	1,330	1,700	2,010	2,300	2,570	2,820	3,050	3,280	3,490	3,700	3,900	4,090
	Non-traversable	1,400	1,650	1,830	1,970	**2,100**	**2,220**	**2,320**	**2,430**	**2,530**	**2,620**	**2,710**	**2,800**	**2,890**
100	Undivided	**200**	**600**	**1,140**	**1,800**	2,580	3,450	4,420	5,480	6,630	7,860	9,160	10,540	11,990
	TWLTL	970	1,470	1,870	2,230	2,540	2,840	3,110	3,380	3,620	3,860	4,090	4,310	4,520
	Non-traversable	1,560	1,850	2,050	2,210	**2,350**	**2,480**	**2,610**	**2,720**	**2,830**	**2,940**	**3,040**	**3,140**	**3,240**

Continued

TABLE 6.5
(Continued)

Access		Annual Average Daily Traffic												
Point Density	**Median Type**	**26,000**	**28,000**	**30,000**	**32,000**	**34,000**	**36,000**	**38,000**	**40,000**	**42,000**	**44,000**	**46,000**	**48,000**	**50,000**
10	Undivided	4,530	5,100	5,700	6,330	6,980	7,650	8,350	9,070	9,810	10,580	11,370	12,180	13,010
	TWLTL	1,860	1,940	2,020	2,110	2,180	2,260	2,340	2,410	2,480	2,560	2,630	2,700	2,760
	Non-traversable	**1,170**	**1,200**	**1,240**	**1,270**	**1,310**	**1,340**	**1,380**	**1,410**	**1,450**	**1,480**	**1,520**	**1,550**	**1,590**
20	Undivided	5,040	5,680	6,350	7,050	7,770	8,520	9,300	10,100	10,930	11,780	12,660	13,560	14,490
	TWLTL	2,050	2,140	2,230	2,320	2,410	2,500	2,580	2,660	2,740	2,820	2,900	2,970	3,050
	Non-traversable	**1,310**	**1,350**	**1,390**	**1,430**	**1,460**	**1,500**	**1,540**	**1,580**	**1,620**	**1,660**	**1,700**	**1,740**	**1,780**
30	Undivided	5,620	6,330	7,070	7,850	8,660	9,490	10,360	11,250	12,180	13,130	14,110	15,110	16,150
	TWLTL	2,260	2,360	2,460	2,560	2,660	2,750	2,850	2,940	3,020	3,110	3,200	3,280	3,360
	Non-traversable	**1,460**	**1,510**	**1,550**	**1,600**	**1,640**	**1,680**	**1,730**	**1,770**	**1,810**	**1,860**	**1,900**	**1,950**	**1,990**
40	Undivided	6,260	7,050	7,880	8,750	9,640	10,580	11,540	12,540	13,570	14,630	15,720	16,840	18,000
	TWLTL	2,490	2,610	2,720	2,830	2,930	3,040	3,140	3,240	3,340	3,430	3,530	3,620	3,710
	Non-traversable	**1,640**	**1,690**	**1,740**	**1,790**	**1,840**	**1,880**	**1,930**	**1,980**	**2,030**	**2,080**	**2,130**	**2,180**	**2,230**
50	Undivided	6,970	7,860	8,780	9,740	10,750	11,790	12,860	13,980	15,120	16,310	17,520	18,770	20,060
	TWLTL	2,750	2,880	3,000	3,120	3,240	3,350	3,470	3,580	3,680	3,790	3,890	4,000	4,100
	Non-traversable	**1,830**	**1,890**	**1,950**	**2,000**	**2,060**	**2,110**	**2,170**	**2,220**	**2,270**	**2,330**	**2,380**	**2,440**	**2,490**
60	Undivided	7,770	8,750	9,790	10,860	11,980	13,140	14,340	15,580	16,860	18,180	19,530	20,930	22,360
	TWLTL	3,040	3,180	3,310	3,450	3,580	3,700	3,830	3,950	4,070	4,180	4,300	4,410	4,520
	Non-traversable	**2,060**	**2,120**	**2,180**	**2,240**	**2,300**	**2,360**	**2,420**	**2,490**	**2,550**	**2,610**	**2,670**	**2,730**	**2,790**
70	Undivided	8,660	9,760	10,910	12,110	13,350	14,640	15,980	17,370	18,790	20,260	21,780	23,330	24,930
	TWLTL	3,360	3,510	3,660	3,810	3,950	4,090	4,220	4,360	4,490	4,620	4,750	4,870	4,990
	Non-traversable	**2,300**	**2,370**	**2,440**	**2,510**	**2,580**	**2,650**	**2,720**	**2,780**	**2,850**	**2,920**	**2,990**	**3,050**	**3,120**
80	Undivided	9,650	10,880	12,160	13,490	14,880	16,330	17,820	19,360	20,950	22,590	24,280	26,020	27,800
	TWLTL	3,710	3,880	4,040	4,200	4,360	4,520	4,670	4,810	4,960	5,100	5,240	5,380	5,510
	Non-traversable	**2,580**	**2,660**	**2,740**	**2,810**	**2,890**	**2,970**	**3,040**	**3,120**	**3,190**	**3,270**	**3,340**	**3,420**	**3,500**
90	Undivided	10,760	12,120	13,550	15,050	16,590	18,200	19,870	21,590	23,360	25,190	27,080	29,010	31,000
	TWLTL	4,090	4,280	4,470	4,640	4,820	4,990	5,150	5,320	5,480	5,640	5,790	5,940	6,090
	Non-traversable	**2,890**	**2,980**	**3,070**	**3,150**	**3,240**	**3,320**	**3,410**	**3,490**	**3,580**	**3,660**	**3,750**	**3,830**	**3,920**
100	Undivided	11,990	13,520	15,110	16,780	18,500	20,300	22,160	24,080	26,060	28,100	30,200	32,360	34,570
	TWLTL	4,520	4,730	4,930	5,130	5,320	5,510	5,700	5,880	6,050	6,230	6,400	6,560	6,730
	Non-traversable	**3,240**	**3,340**	**3,440**	**3,530**	**3,630**	**3,720**	**3,820**	**3,910**	**4,010**	**4,100**	**4,200**	**4,290**	**4,390**

Note: All costs in black are estimates based on limited data and should be treated with caution. The median type with the lowest expected crash cost for given AADT and access point density are boldface.

TABLE 6.6
Annual comprehensive crash cost (1,000 USD/mile), speed limit = 55 mph

Access Point Density	Median Type	Annual Average Daily Traffic 2,000	4,000	6,000	8,000	10,000	12,000	14,000	16,000	18,000	20,000	22,000	24,000	26,000
10	Undivided	70	210	390	620	890	1,190	1,520	1,880	2,270	2,690	3,140	3,610	4,100
	TWLTL	400	610	780	920	1,050	1,170	1,290	1,390	1,490	1,590	1,680	1,780	1,860
	Non-traversable	450	530	590	630	670	710	740	770	800	830	860	890	910
20	Undivided	80	230	440	690	990	1,320	1,690	2,100	2,530	3,000	3,500	4,020	4,580
	TWLTL	450	670	860	1,020	1,160	1,290	1,420	1,540	1,650	1,760	1,860	1,960	2,060
	Non-traversable	510	590	660	710	750	790	830	860	900	930	960	990	1,020
30	Undivided	90	260	490	770	1,100	1,470	1,880	2,340	2,820	3,340	3,900	4,480	5,100
	TWLTL	490	740	950	1,120	1,280	1,430	1,570	1,700	1,820	1,940	2,050	2,160	2,270
	Non-traversable	570	670	740	790	840	890	930	970	1,010	1,040	1,080	1,110	1,150
40	Undivided	90	280	540	860	1,220	1,640	2,100	2,600	3,150	3,730	4,340	5,000	5,690
	TWLTL	540	820	1,040	1,240	1,410	1,580	1,730	1,870	2,010	2,140	2,270	2,390	2,510
	Non-traversable	630	750	820	890	940	990	1,040	1,080	1,130	1,170	1,210	1,240	1,280
50	Undivided	110	320	600	950	1,360	1,830	2,340	2,900	3,510	4,160	4,840	5,570	6,340
	TWLTL	600	910	1,150	1,370	1,560	1,740	1,910	2,070	2,220	2,360	2,500	2,640	2,770
	Non-traversable	710	830	920	990	1,060	1,110	1,160	1,210	1,260	1,310	1,350	1,390	1,440
60	Undivided	120	350	670	1,060	1,520	2,040	2,610	3,240	3,910	4,630	5,400	6,220	7,070
	TWLTL	660	1,000	1,270	1,510	1,730	1,920	2,110	2,280	2,450	2,610	2,760	2,910	3,050
	Non-traversable	790	930	1,030	1,110	1,180	1,250	1,300	1,360	1,410	1,460	1,510	1,560	1,610
70	Undivided	130	390	750	1,190	1,700	2,270	2,910	3,610	4,360	5,170	6,030	6,930	7,890
	TWLTL	730	1,110	1,410	1,670	1,910	2,120	2,330	2,520	2,710	2,880	3,050	3,220	3,370
	Non-traversable	890	1,050	1,160	1,250	1,320	1,400	1,460	1,520	1,580	1,640	1,690	1,750	1,800
80	Undivided	150	440	830	1,320	1,890	2,530	3,250	4,020	4,860	5,760	6,720	7,740	8,800
	TWLTL	810	1,220	1,550	1,840	2,110	2,350	2,570	2,790	2,990	3,190	3,370	3,550	3,730
	Non-traversable	990	1,170	1,300	1,400	1,480	1,560	1,640	1,710	1,770	1,840	1,900	1,960	2,020
90	Undivided	160	490	930	1,470	2,110	2,820	3,620	4,490	5,430	6,430	7,500	8,630	9,820
	TWLTL	900	1,350	1,720	2,040	2,330	2,590	2,840	3,080	3,300	3,520	3,730	3,930	4,120
	Non-traversable	1,110	1,310	1,450	1,560	1,660	1,750	1,830	1,910	1,990	2,060	2,130	2,200	2,260
100	Undivided	180	540	1,040	1,640	2,350	3,150	4,040	5,010	6,050	7,170	8,370	9,630	10,960
	TWLTL	990	1,490	1,900	2,250	2,570	2,870	3,140	3,400	3,650	3,890	4,120	4,340	4,550
	Non-traversable	1,250	1,470	1,620	1,750	1,860	1,960	2,050	2,140	2,230	2,310	2,380	2,460	2,530

Continued

TABLE 6.6
(Continued)

Access Point Density	Median Type	26,000	28,000	30,000	32,000	34,000	36,000	38,000	40,000	42,000	44,000	46,000	48,000	50,000
		Annual Average Daily Traffic												
10	Undivided	4,100	4,620	5,170	5,740	6,330	6,940	7,570	8,230	8,900	9,600	10,310	11,050	11,800
	TWLTL	1,860	1,950	2,030	2,110	2,190	2,270	2,340	2,410	2,490	2,560	2,630	2,700	2,760
	Non-traversable	**910**	**940**	**970**	**990**	**1,020**	**1,050**	**1,070**	**1,100**	**1,120**	**1,150**	**1,170**	**1,200**	**1,230**
20	Undivided	4,580	5,160	5,760	6,400	7,050	7,740	8,440	9,170	9,930	10,700	11,500	12,320	13,160
	TWLTL	2,060	2,150	2,240	2,330	2,420	2,500	2,580	2,660	2,740	2,820	2,900	2,980	3,050
	Non-traversable	**1,020**	**1,050**	**1,080**	**1,110**	**1,140**	**1,170**	**1,200**	**1,230**	**1,260**	**1,290**	**1,310**	**1,340**	**1,370**
30	Undivided	5,100	5,750	6,430	7,130	7,870	8,630	9,410	10,230	11,070	11,930	12,830	13,740	14,680
	TWLTL	2,270	2,370	2,470	2,570	2,670	2,760	2,850	2,940	3,030	3,120	3,200	3,280	3,370
	Non-traversable	**1,150**	**1,180**	**1,210**	**1,240**	**1,280**	**1,310**	**1,340**	**1,370**	**1,410**	**1,440**	**1,470**	**1,500**	**1,540**
40	Undivided	5,690	6,410	7,170	7,950	8,770	9,620	10,500	11,410	12,350	13,310	14,310	15,330	16,370
	TWLTL	2,510	2,620	2,730	2,840	2,940	3,050	3,150	3,250	3,340	3,440	3,530	3,620	3,720
	Non-traversable	**1,280**	**1,320**	**1,360**	**1,390**	**1,430**	**1,470**	**1,500**	**1,540**	**1,570**	**1,610**	**1,650**	**1,680**	**1,720**
50	Undivided	6,340	7,150	7,990	8,870	9,780	10,730	11,710	12,720	13,770	14,850	15,960	17,100	18,270
	TWLTL	2,770	2,890	3,010	3,130	3,250	3,360	3,480	3,580	3,690	3,800	3,900	4,000	4,100
	Non-traversable	**1,440**	**1,480**	**1,520**	**1,560**	**1,600**	**1,640**	**1,680**	**1,720**	**1,760**	**1,800**	**1,840**	**1,880**	**1,920**
60	Undivided	7,070	7,970	8,910	9,890	10,910	11,970	13,060	14,200	15,360	16,560	17,800	19,070	20,380
	TWLTL	3,050	3,190	3,330	3,460	3,590	3,720	3,840	3,960	4,080	4,190	4,310	4,420	4,530
	Non-traversable	**1,610**	**1,660**	**1,700**	**1,750**	**1,790**	**1,840**	**1,880**	**1,930**	**1,970**	**2,020**	**2,060**	**2,110**	**2,150**
70	Undivided	7,890	8,890	9,940	11,040	12,170	13,350	14,580	15,840	17,140	18,480	19,860	21,280	22,740
	TWLTL	3,370	3,530	3,680	3,820	3,960	4,100	4,240	4,370	4,500	4,630	4,760	4,880	5,000
	Non-traversable	**1,800**	**1,850**	**1,910**	**1,960**	**2,010**	**2,060**	**2,110**	**2,160**	**2,210**	**2,260**	**2,310**	**2,360**	**2,410**
80	Undivided	8,800	9,920	11,090	12,310	13,580	14,900	16,260	17,670	19,120	20,620	22,160	23,750	25,370
	TWLTL	3,730	3,900	4,060	4,220	4,380	4,530	4,680	4,830	4,970	5,120	5,250	5,390	5,530
	Non-traversable	**2,020**	**2,080**	**2,130**	**2,190**	**2,250**	**2,310**	**2,360**	**2,420**	**2,470**	**2,530**	**2,590**	**2,640**	**2,700**
90	Undivided	9,820	11,070	12,380	13,740	15,160	16,630	18,150	19,720	21,340	23,010	24,730	26,500	28,310
	TWLTL	4,120	4,310	4,490	4,670	4,840	5,010	5,170	5,340	5,500	5,650	5,810	5,960	6,110
	Non-traversable	**2,260**	**2,330**	**2,390**	**2,460**	**2,520**	**2,580**	**2,650**	**2,710**	**2,770**	**2,830**	**2,900**	**2,960**	**3,020**
100	Undivided	10,960	12,350	13,810	15,330	16,910	18,550	20,250	22,010	23,820	25,680	27,600	29,580	31,600
	TWLTL	4,550	4,760	4,960	5,160	5,350	5,540	5,720	5,900	6,070	6,250	6,420	6,580	6,750
	Non-traversable	**2,530**	**2,610**	**2,680**	**2,750**	**2,820**	**2,890**	**2,960**	**3,030**	**3,100**	**3,170**	**3,240**	**3,310**	**3,380**

Note: All costs in black are estimates based on limited data and should be treated with caution. The median type with the lowest expected crash cost for given AADT and access point density are boldface.

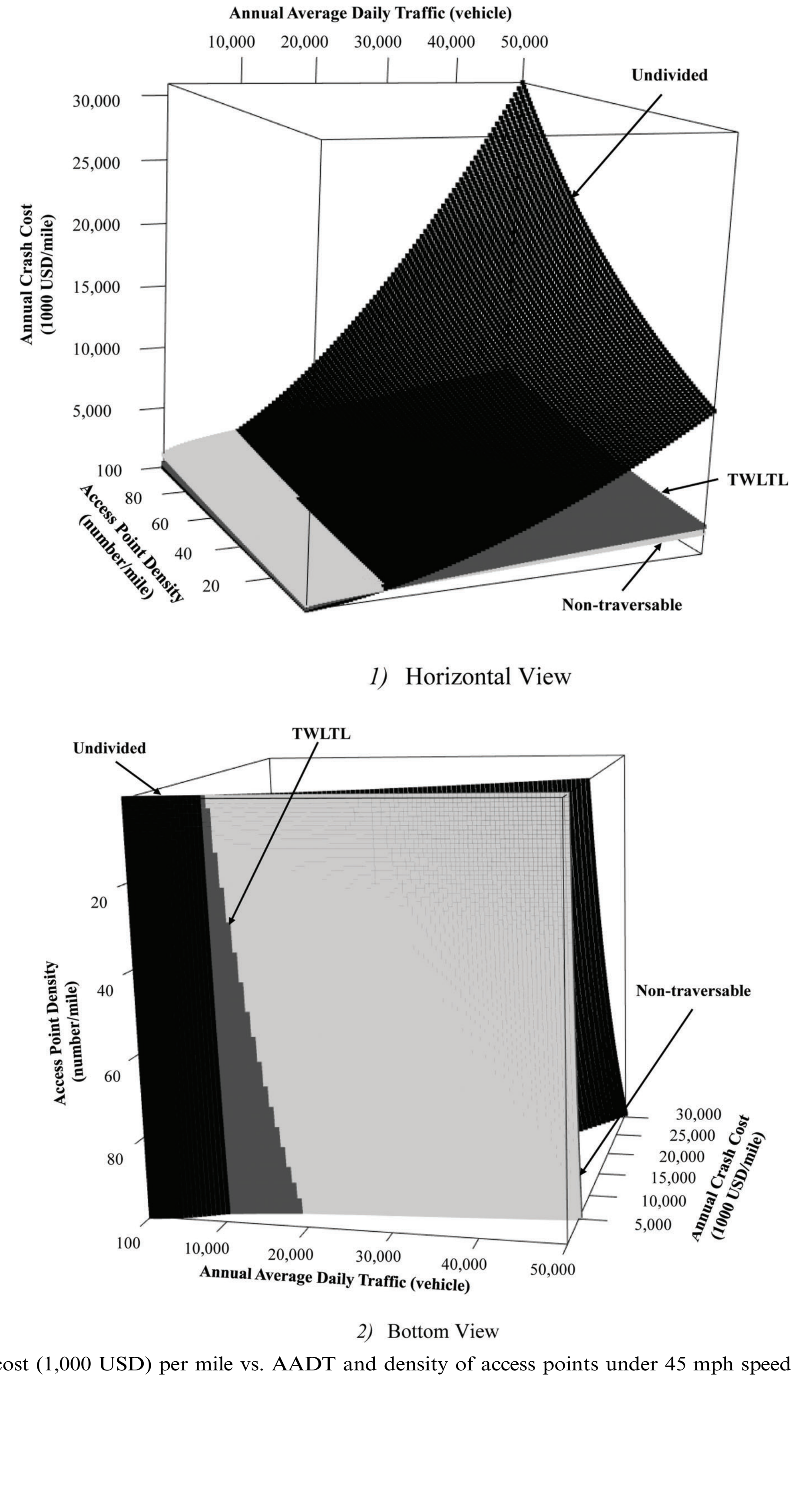
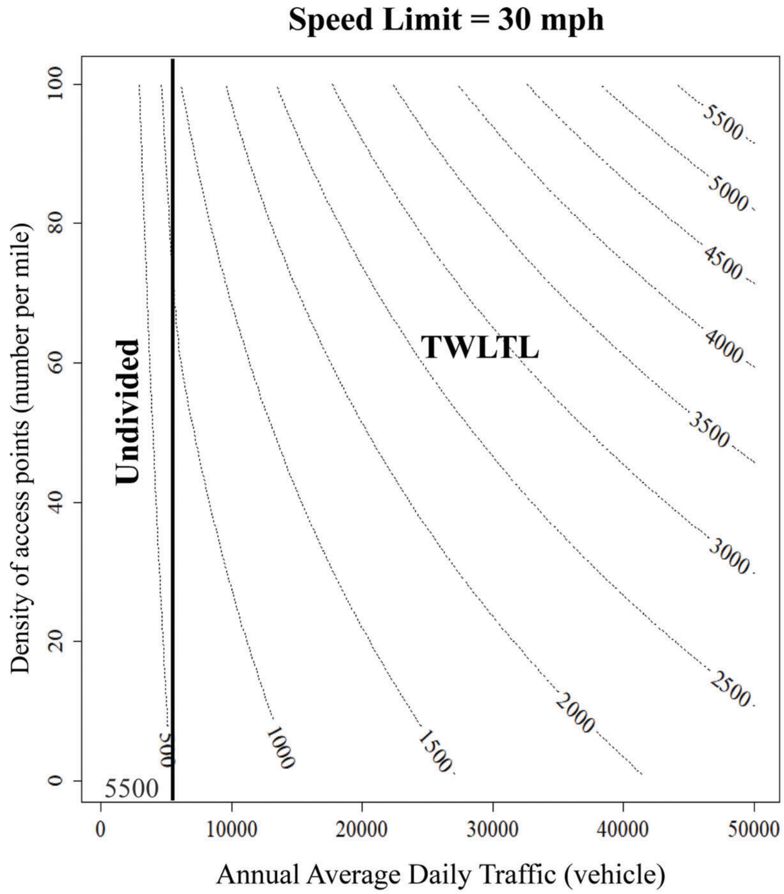
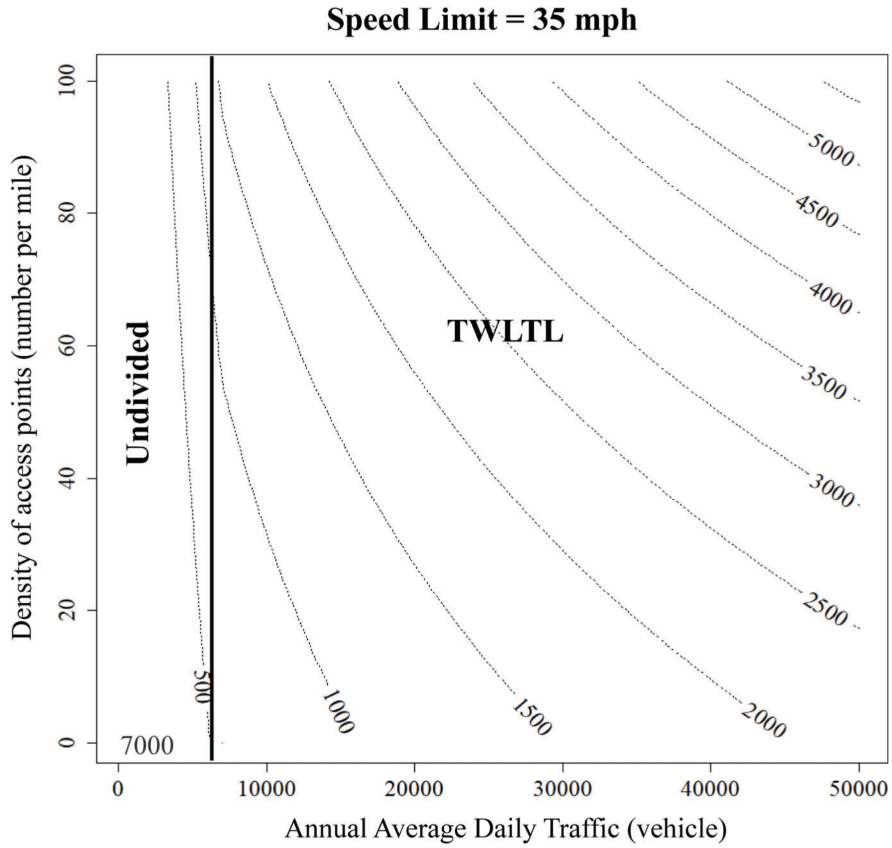


Figure 6.1 Crash cost (1,000 USD) per mile vs. AADT and density of access points under 45 mph speed limit in 3D space.



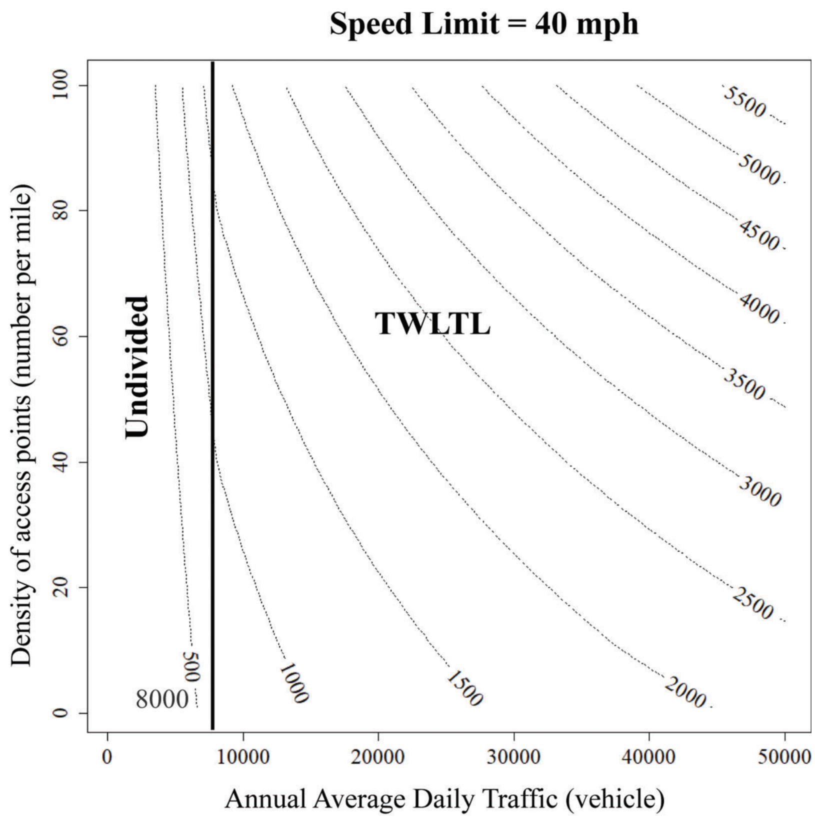
Note: Contour lines represent annual crash cost per mile in 1,000 USD (2022). Non-traversable median always recommended for six-lane segments.

Figure 6.2 Labelled safest median treatment ranges (speed limit = 30 mph).



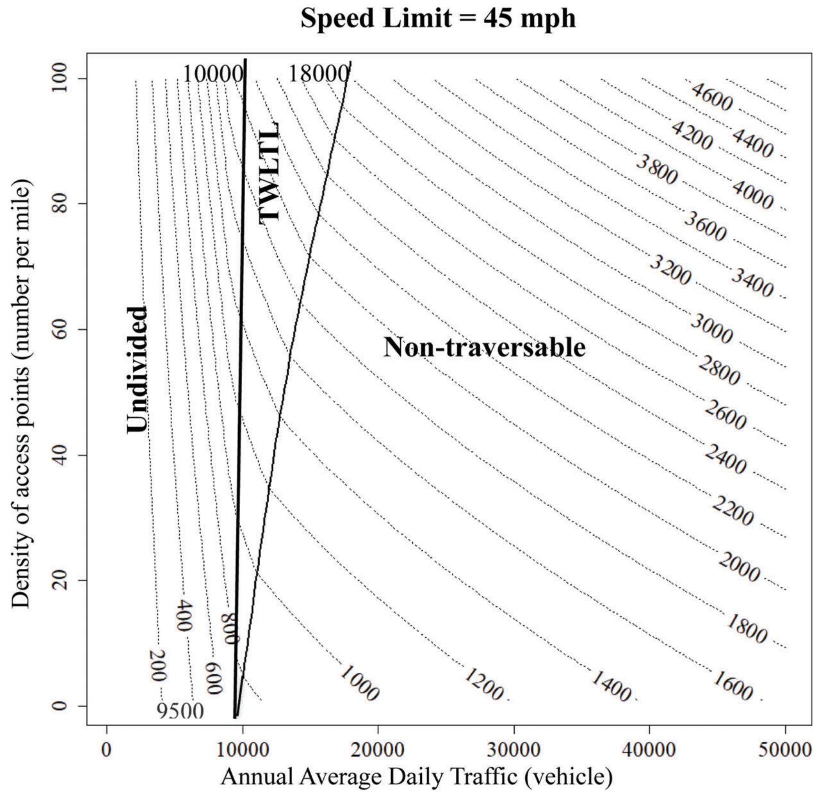
Note: Contour lines represent annual crash cost per mile in 1,000 USD (2022). Non-traversable median always recommended for six-lane segments.

Figure 6.3 Labelled safest median treatment ranges (speed limit = 35 mph).



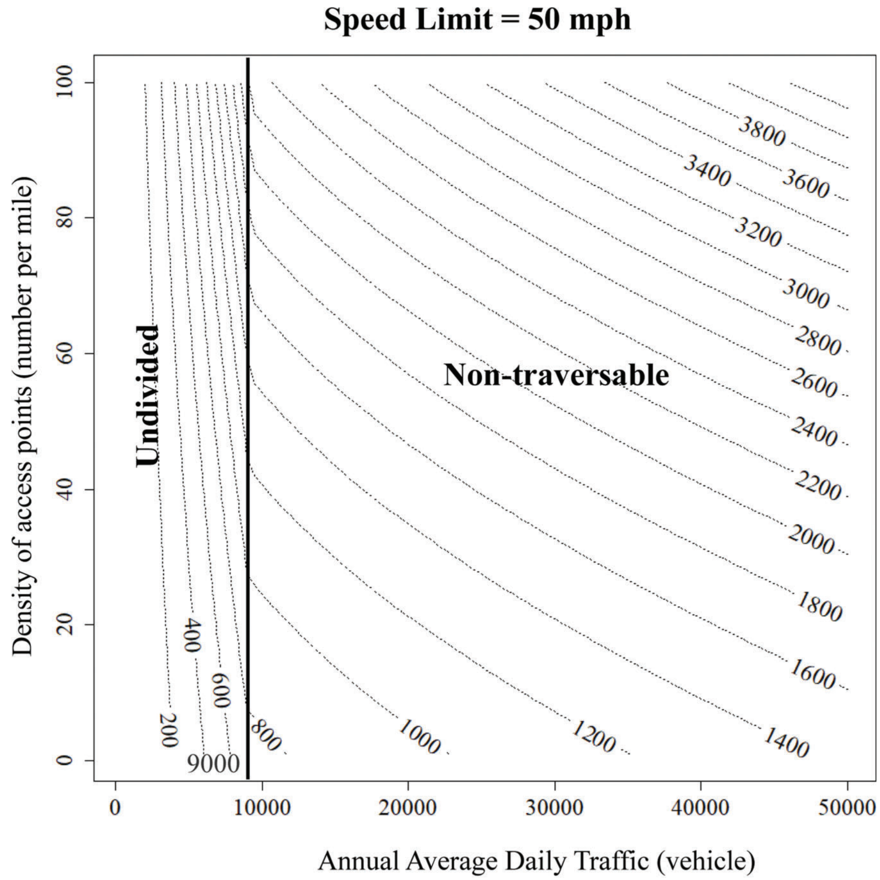
Note: Contour lines represent annual crash cost per mile in 1,000 USD (2022). Non-traversable median always recommended for six-lane segments.

Figure 6.4 Labelled safest median treatment ranges (speed limit = 40 mph).



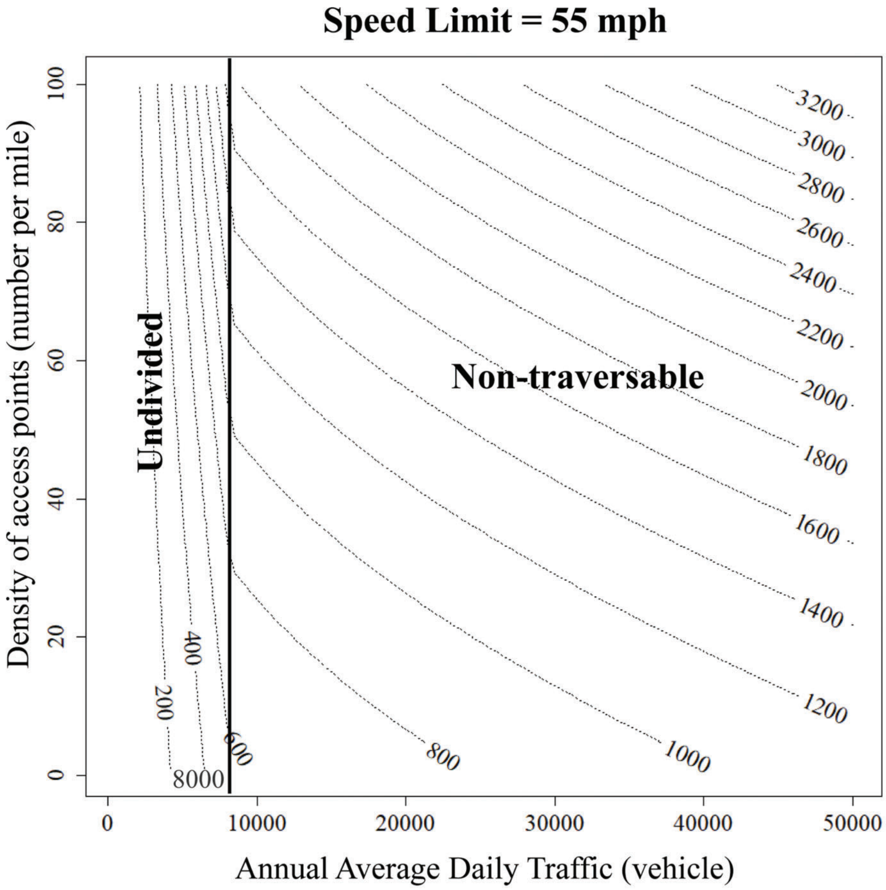
Note: Contour lines represent annual crash cost per mile in 1,000 USD (2022). Non-traversable median always recommended for six-lane segments.

Figure 6.5 Labelled safest median treatment ranges (speed limit = 45 mph).



Note: Contour lines represent annual crash cost per mile in 1,000 USD (2022). Non-traversable median always recommended for six-lane segments.

Figure 6.6 Labelled safest median treatment ranges (speed limit = 50 mph).



Note: Contour lines represent annual crash cost per mile in 1,000 USD (2022). Non-traversable median always recommended for six-lane segments.

Figure 6.7 Labelled safest median treatment ranges (speed limit = 55 mph).

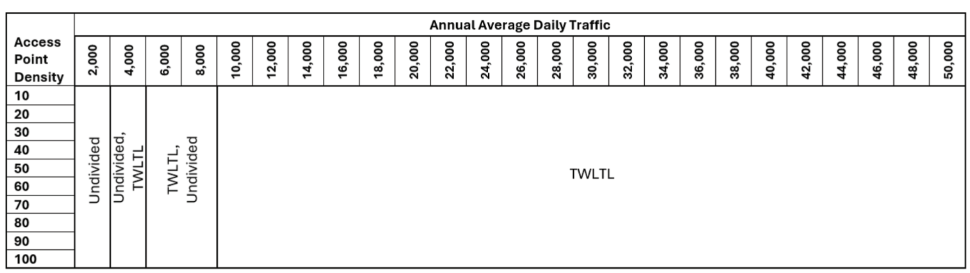


Figure 6.8 Preferable median treatment for 30 mph, maximum cost ratio 1.5.

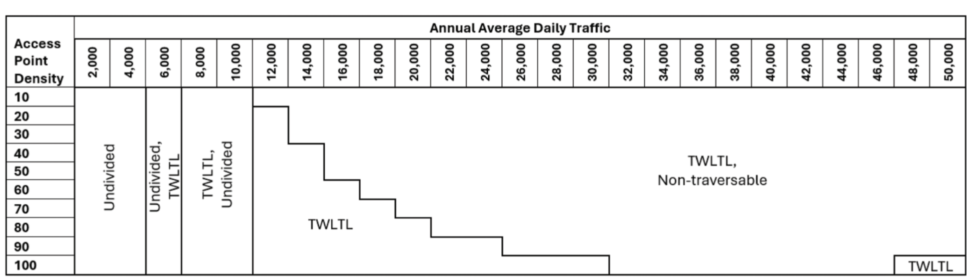
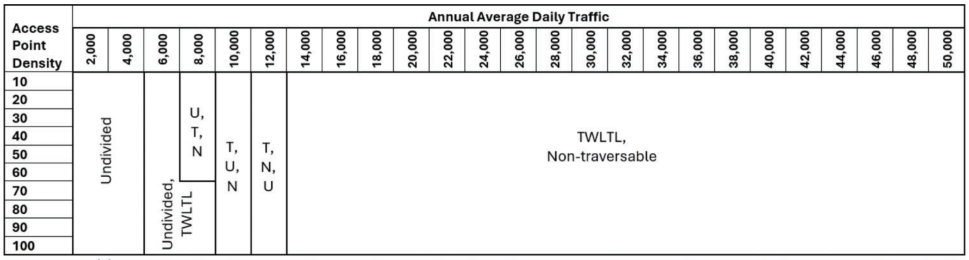
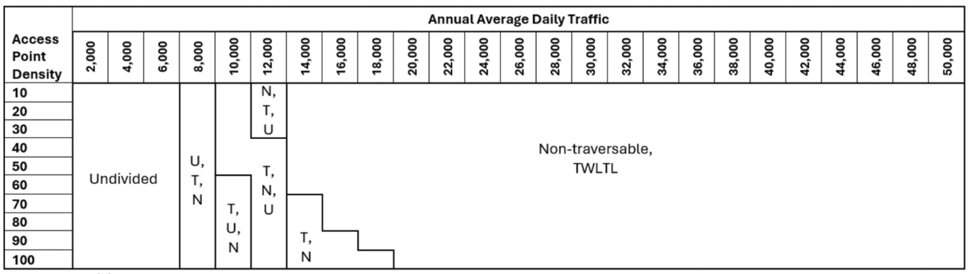


Figure 6.9 Preferable median treatment for 35 mph, maximum cost ratio 1.5.



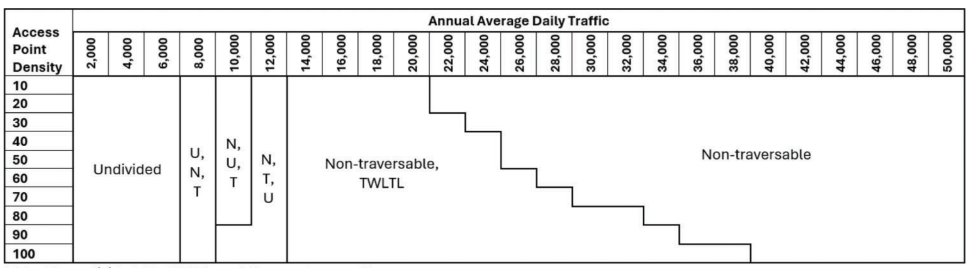
Note: U = undivided, T = TWLTL, and N = non-traversable.

Figure 6.10 Preferable median treatment for 40 mph, maximum cost ratio 1.5.



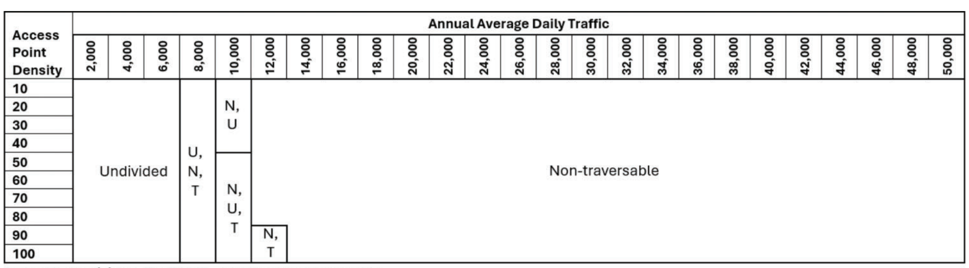
Note: U = undivided, T = TWLTL, and N = non-traversable.

Figure 6.11 Preferable median treatment for 45 mph, maximum cost ratio 1.5.



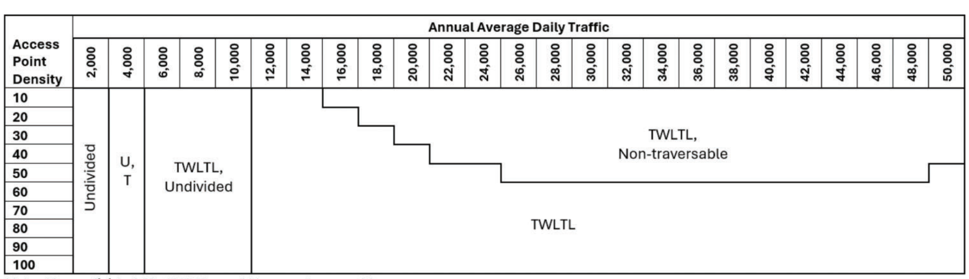
Note: U = undivided, T = TWLTL, and N = non-traversable.

Figure 6.12 Preferable median treatment for 50 mph, maximum cost ratio 1.5.



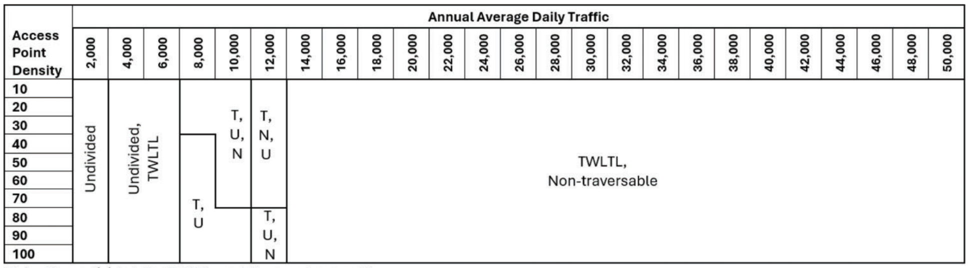
Note: U = undivided, T = TWLTL, and N = non-traversable.

Figure 6.13 Preferable median treatment for 55 mph, maximum cost ratio 1.5.



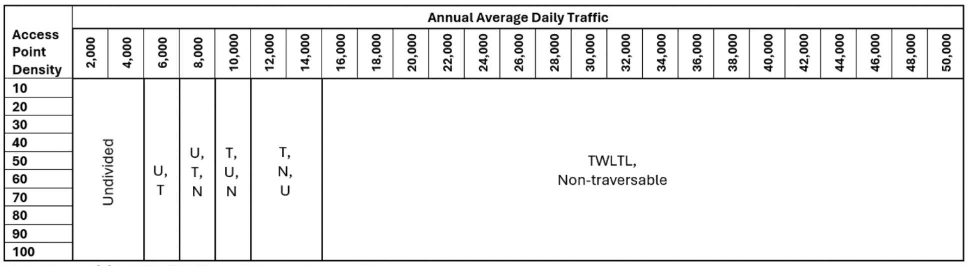
Note: U = undivided, T = TWLTL, and N = non-traversable.

Figure 6.14 Preferable median treatment for 30 mph, maximum cost ratio 1.75.



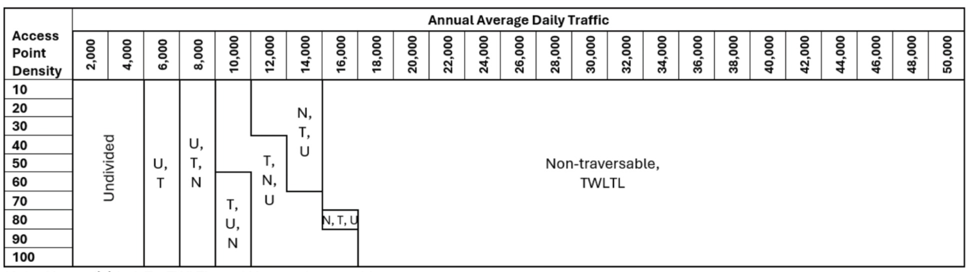
Note: U = undivided, T = TWLTL, and N = non-traversable.

Figure 6.15 Preferable median treatment for 35 mph, maximum cost ratio 1.75.



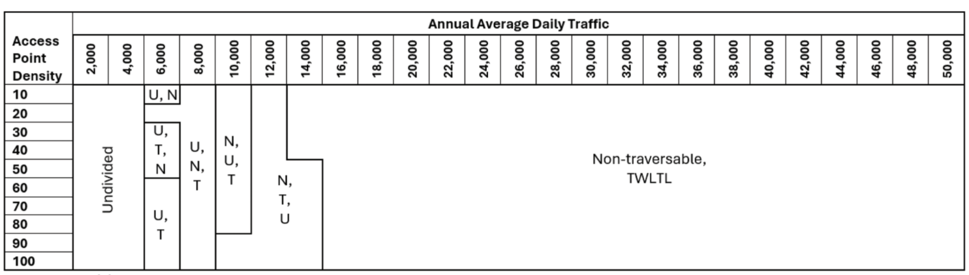
Note: U = undivided, T = TWLTL, and N = non-traversable.

Figure 6.16 Preferable median treatment for 40 mph, maximum cost ratio 1.75.



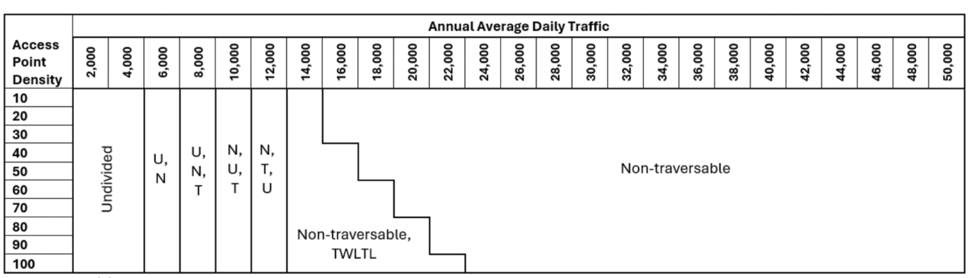
Note: U = undivided, T = TWLTL, and N = non-traversable.

Figure 6.17 Preferable median treatment for 45 mph, maximum cost ratio 1.75.



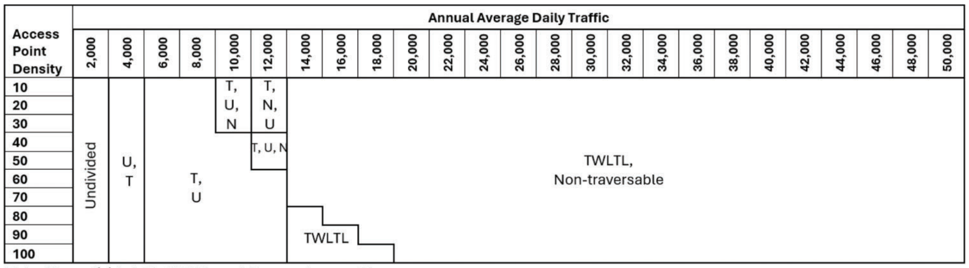
Note: U = undivided, T = TWLTL, and N = non-traversable.

Figure 6.18 Preferable median treatment for 50 mph, maximum cost ratio 1.75.



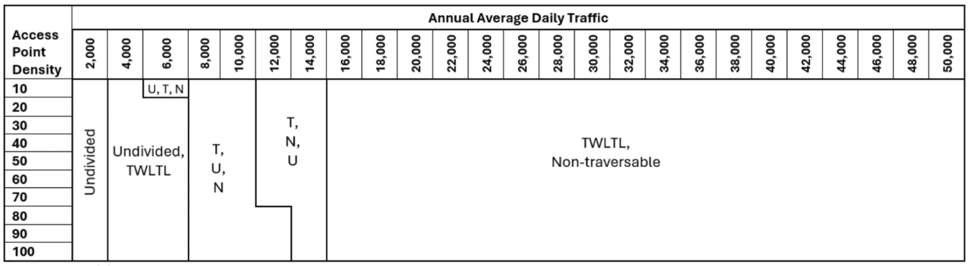
Note: U = undivided, T = TWLTL, and N = non-traversable.

Figure 6.19 Preferable median treatment for 55 mph, maximum cost ratio 1.75.



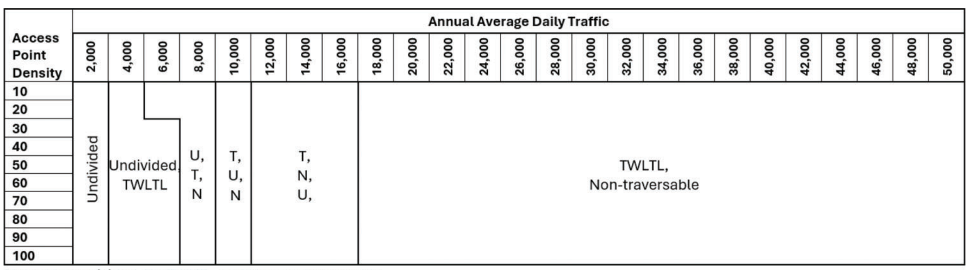
Note: U = undivided, T = TWLTL, and N = non-traversable.

Figure 6.20 Preferable median treatment for 30 mph, maximum cost ratio 2.



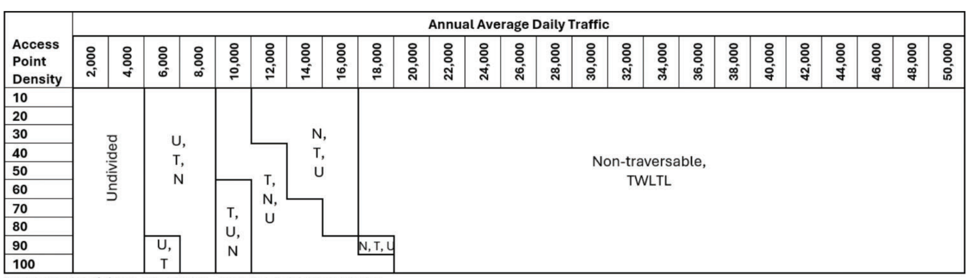
Note: U = undivided, T = TWLTL, and N = non-traversable.

Figure 6.21 Preferable median treatment for 35 mph, maximum cost ratio 2.



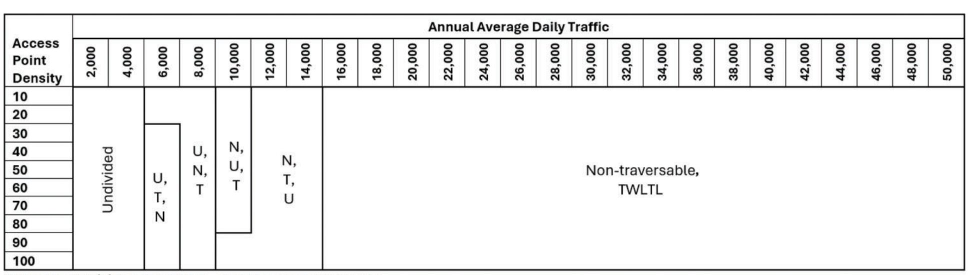
Note: U = undivided, T = TWLTL, and N = non-traversable.

Figure 6.22 Preferable median treatment for 40 mph, maximum cost ratio 2.



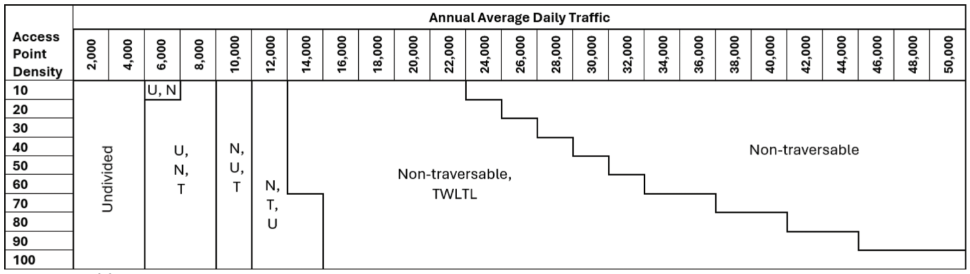
Note: U = undivided, T = TWLTL, and N = non-traversable.

Figure 6.23 Preferable median treatment for 45 mph, maximum cost ratio 2.



Note: U = undivided, T = TWLTL, and N = non-traversable.

Figure 6.24 Preferable median treatment for 50 mph, maximum cost ratio 2.



Note: U = undivided, T = TWLTL, and N = non-traversable.

Figure 6.25 Preferable median treatment for 55 mph, maximum cost ratio 2.

TABLE 6.7
Median treatment application condition summary (lowest cost)

Lane Number	Speed Limit	Median Type	Conditions with Lowest Crash Costs for the Considered Median Treatments
Two to Four-Lane	30	Undivided	AADT < 5,500 veh/day
		TWLTL	AADT > 5,500 veh/day
		Non-traversable	Not enough data
	35	Undivided	AADT < 8,000 veh/day
		TWLTL	AADT > 8,000 veh/day
		Non-traversable	Not enough data
	40	Undivided	AADT < 7,000 veh/day
		TWLTL	AADT > 7,000 veh/day
		Non-traversable	–
	45	Undivided	AADT < 9,500 veh/day
		TWLTL	When 9,500 < AADT < 18,000 veh/day and access density > (AADT/180)
		Non-traversable	When 9,500 < AADT < 18,000 veh/day and access density < (AADT/180) or when AADT > 18,000 veh/day
	50	Undivided	AADT < 9,000 veh/day
		TWLTL	–
		Non-traversable	AADT > 9,000 veh/day
	55	Undivided	AADT < 8,000 veh/day
		TWLTL	–
		Non-traversable	AADT > 8,000 veh/day
	60	Non-traversable	Advised for all conditions
Six-Lane	All	Non-traversable	Advised for all conditions

TABLE 6.8
Median treatment application condition summary (MCR = 1.5)

Lane Number	Speed Limit	Median Type	Conditions with Lowest Crash Costs or MCR = 1.5
Two to Four-Lane	30	Undivided	AADT < 9,000 veh/day
		TWLTL	AADT > 3,000 veh/day
		Non-traversable	Not enough data
	35	Undivided	AADT < 11,000 veh/day
		TWLTL	AADT > 5,000 veh/day
		Non-traversable	Not enough data
	40	Undivided	AADT < 13,000 veh/day
		TWLTL	AADT > 5,000 veh/day
		Non-traversable	AADT > 7,000 veh/day
	45	Undivided	AADT < 13,000 veh/day
		TWLTL	AADT > 7,000 veh/day
		Non-traversable	AADT > 7,000 veh/day
	50	Undivided	AADT < 13,000 veh/day
		TWLTL	When 7,000 < AADT < 21,000 or when 2,1000 < AADT < 38,000 veh/day and access density > (AADT/250 – 60)
		Non-traversable	When 2,1000 < AADT < 38,000 veh/day and access density < (AADT/250 – 60) or when AADT > 38,000
	55	Undivided	AADT < 11,000 veh/day
		TWLTL	7,000 veh/day < AADT < 10,000 veh/day
		Non-traversable	AADT > 7,000 veh/day
	60	Non-traversable	Advised for all conditions
Six-Lane	All	Non-traversable	Advised for all conditions

7. CONCLUSIONS

This study investigated traffic safety on road segments with the three median treatments: undivided cross-section, continuous two-way left-turn lane (TWLTL), and non-traversable median. Several critical safety factors were identified and quantified on suburban arterials analysis, where the interaction between the through and accessing/exiting traffic may cause safety issues. To account for complex endogeneity among safety, crashes, speed limits, simultaneous equations were used to estimate true connection between safety and risk factors. The identified important risk factors include traffic volume (increases crash frequency), density of access points (increases crash frequency), road geometric standard represented with speed limit (decreases crash frequency) and median treatments (varying across conditions).

As expected, the results indicate that non-traversable medians are recommendable where both the traffic demand tends to be high while the density of access points is low. For the speed limit greater than 55 mph, non-traversable median is recommended. In all circumstances, when the number of through lanes of a segment is greater than four, the non-traversable median is recommended.

The specific boundaries between TWLTL and non-traversable median varies by speed limits. When the speed limit is lower than 45 mph, TWLTL alternatives should be considered. Undivided cross-sections may be considered only where the local conditions do not provide sufficient space for other cross-section types.

This study focused on the safety benefits of the studied median treatment alternatives. A full benefit-cost analysis must also include the construction and maintenance costs within the life-cycle framework. The developed equations for estimating safety benefits can be easily used in this full economic analysis framework.

The results of this study provide a useful perspective on median treatments' safety performance and how the median type interacts with other critical factors. The implementation results include convenient tables that provide comprehensive annual crash costs for multiple scenarios represented with the data available during the study. These costs may be directly used to select a median treatment based on its safety benefits or be an input to a comprehensive analysis that includes the construction and maintenance costs.

The application of the models includes selecting a median treatment with the lowest or comparable annual crash cost per mile among the three median types. Simple multiplication of the selected unit crash cost by the road segment length (in miles) delivers the important input to a benefit-cost analysis. The INDOT Road Hazard Analysis Tool (RoadHAT) can be used to perform calculations.

There are three types of tools provided in this report to consider.

1. The *crash cost tables* with the expected crash costs per mile depending on speed limit, median treatment, access point density, and AADT.
2. The *corresponding selection figures* that could be used alternatively to the crash cost tables.
3. The *alternative selection tables* with labeled median treatments that perform best or close to the best one.

REFERENCES

AECOM Transportation. (2009). *Access management guide*. Indiana Department of Transportation.

Alluri, P., Gan, A., Haleem, K., Miranda, S., Echezabal, E., Diaz, A., & Ding, S. (2012). *Before-and-after safety study of roadways where medians have been added* (Contract No. BDK80 977-18). Lehman Center for Transportation Research.

Avelar, R. E., Dixon, K. K., Brown, L. S., Mecham, M. E., & Schalkwyk, I. V. (2013). Influence of land use and driveway placement on safety performance of arterial highways. *Transportation Research Record*, *2398*(1), 101–109. https://doi.org/10.3141/2398-12

Box, P. C. (1969). Driveway accident and volume studies, Part 1: General relationships. *Public Safety Systems*, July/Aug. 1969, pp. 15–18.

Brown, H. C., Labi, S., Tarko, A. P., & Fricker, J. D. (1998). *A tool for evaluating access control on high speed urban arterials, Part I* (Joint Transportation Research Program Publication No. FHWA/IN/JTRP-98/07-I, 2144). West Lafayette, Indiana: Purdue University. https://doi.org/10.5703/1288284313131

Chen, C., Wu, Q., Zhang, G., Liu, X. C., & Prevedouros, P. D. (2018). Extracting arterial access density impacts on safety performance based on clustering and computational analysis. *Journal of Transportation Engineering, Part A: Systems*, *144*(4), 04018008. https://digitalcommons.usf.edu/cutr_facpub/84

Eisele, W. L., & Frawley, W. E. (2005). Estimating the safety and operational impact of raised medians and driveway density: Experiences from Texas and Oklahoma case studies. *Transportation Research Record*, *1931*(1), 108–116.

Gluck, J., Levinson, H. S., & Stover, V. (1999). *Impacts of access management techniques* (NCHRP Report 420). National Cooperative Highway Research Program.

Google. (2023, July). [Google Street View image of 5825 S Scatterfield Rd, Anderson, IN 46013]. https://tinyurl.com/3m3pwcs9

Haleem, K., Abdel-Aty, M., & Mackie, K. (2010). Using a reliability process to reduce uncertainty in predicting crashes at unsignalized intersections. *Accident Analysis & Prevention*, *42*(2), 654–666. https://doi.org/10.1016/j.aap.2009.10.012

IndianaMap. (2024). *Satellite Imagery* [Map]. Indiana Geographic Information Office. https://viewer.indianamap.org/

INDOT. (2013a). Chapter 45—Cross section elements. In *Indiana Department of Transportation—2013 Design Manual* (pp. 20–24). Indiana Department of Transportation. https://www.in.gov/dot/div/contracts/design/Part%203/Chapter%2045%20-%20Cross-Section%20Elements.pdf

INDOT. (2013b). Chapter 46—Intersections at-grade. In *Indiana Department of Transportation—2013 Design Manual* (pp. 33–36). Indiana Department of Transportation. https://www.in.gov/dot/div/contracts/design/Part%203/Chapter%2046%20-%20Intersections%20At-Grade.pdf

Liu, C., Zhao, M., Li, W., & Sharma, A. (2018). Multivariate random parameters zero-inflated negative binomial regression for analyzing urban midblock crashes. *Analytic Methods in Accident Research*, *17*, 32–46.

Maryam Mousavi, S., Dixon, K. K., & Fitzpatrick, K. (2022). Determining variables that influence the operation and safety of median openings in close proximity to signalized intersections. *Transportation Research Record*, *2676*(9), 1–12.

McGuirk, W. W., & Satterly, G. T. (1976). *Evaluation of factors influencing driveway accidents: Technical paper* (Joint Highway Research Project Publication FHWA/IN/JHRP-76/01). West Lafayette, Indiana: Purdue University. https://doi.org/10.5703/1288284313911

Schultz, G. G., Lewis, J. S., & Boschert, T. (2007). Safety impacts of access management techniques in Utah. *Transportation Research Record*, *1994*(1), 35–42.

Squires, C. A., & Parsonson, P. S. (1989). Accident comparison of raised median and two-way left-turn lane median treatments. *Transportation Research Record*, *1239*, 30–40.

Taylor, W. C., Lim, I., & Lighthizer, D. R. (2001). Effect on crashes after construction of directional median crossovers. *Transportation Research Record*, *1758*(1), 30–35.

APPENDICES

Appendix A. Crash Frequency and Severity Models

Appendix B. Access Point Density Definition

Appendix C. Model

Appendix D. Indiana Crash Frequencies

Appendix E. Sample Distribution

APPENDIX A. CRASH FREQUENCY AND SEVERITY MODELS

The crash frequency is usually modeled using Poisson regression or negative-binomial regression (a generalization of Poisson regression). In both models, the logarithm of the crash count for each segment is treated as the generalized Y, which is assumed to be affected by crash risk factors. Usually, segment length or traffic is treated as the exposure factor, when an offset variable is set and enters on the right-hand side of the equation with a parameter estimate (for log(exposure)) constrained to 1 (Eq. A.1). After estimation of the coefficients β, the crash count is then predicted using Eq. A.2.

$$\log(CrashNum) = \log(Exposure) + \beta_1 Factor_1 + \beta_2 Factor_2 + \cdots \qquad \text{Eq. A.1}$$

$$CrashNum = Exposure * \exp\left(\beta_1 Factor_1 + \beta_2 Factor_2 + \cdots\right) \qquad \text{Eq. A.2}$$

In crash severity analysis, each crash is treated as an observation. Their severity levels vary across different geometry and traffic conditions. Considering the ordinal nature of crash severity levels, property damage (PD), non-incapacitating (BC), incapacitating and fatal (KA), the ordered logit model is used for analysis. The ordered logit model introduces an unobservable latent variable z, which is used as a basis for modeling the ordinal ranking of data. The discrete severity levels were assumed to be associated with this latent variable (Eq. A.3). This variable is mainly specified as a linear function for each observation (Eq. A.4) where X_i is a vector of variables, the median treatment and all other factors that might influence the crash severity, β is a vector of estimated parameters, and ε_i is a random error term.

$$\begin{cases} y = 1, if\ z \le \mu_0 \\ y = 2, if\ \mu_0 < z \le \mu_1 \\ y = 3, if\ z > \mu_1 \end{cases} \qquad \text{Eq. A.3}$$

$$z_i = X_i\beta + \varepsilon_i \qquad \text{Eq. A.4}$$

Following the discussed modeling strategies, both crash frequency model and severity model were estimated. The estimation results are shown in Table A.1 (frequency model) and Table A.2 (severity model).

For the crash frequency model, the logarithm of annual average daily traffic (logAADT) and access point density (AcsDensity) were found to significantly increase crash frequency which is expected because more traffic and more conflicting points will increase crash probability. Nevertheless, the most important factor, the median treatment, was not statistically significant. There is weak significance when the undivided dummy variable interacts with logAADT indicating the difference between undivided and non-traversable median (used as the reference) treatments. But the P-value for the interaction between logAADT and TWLTL (two-way left-turn lane) is too high to claim a statistical difference between TWLTL and non-traversable.

Table A.1 Estimation results of the crash frequency model (negative binominal model)

	Estimate	Std. Error	P-value
Intercept	-4.576	1.691	0.007
logAADT	0.717	0.167	<0.001
AcsDensity	0.0127	0.002	<0.001
logAADT*Undivided	0.036	0.024	0.130
logAADT*TWLTL	0.016	0.016	0.430
Dispersion Parameter		1.23	

Table A.2 Estimation results of the crash severity model (ordered logit model)

	Estimate	Std. Error	P-value
Intercept1	0.972	0.033	<0.001
Intercept2	-1.19	0.109	<0.001
TWLTL	-0.101	0.095	0.285
Undivided	0.154	0.105	0.140
Length	0.285	0.178	0.109
AcsDensity	-0.002	0.001	0.014
SixLane	-0.039	0.100	0.697
TWLTL*SixLane	0.408	0.164	0.013

For the crash severity model, the access point density was found to significantly increase crash severity. Segment length also has a positive effect on crash severity with weak significance. Although not very significant, the median treatment effects indicate that compared to the reference cases (non-traversable), undivided is less safe (positive effect on severity) but two-way left-turn lane is generally safer except for six-lane segments. The positive and significant interaction variable *TWLTL*SixLane* implies that non-traversable median significantly outperforms two-way left-turn lane when there are six lanes.

APPENDIX B. ACCESS POINT DENSITY DEFINITION

To increase the implementation convenience, the safety effect of driveways and unsignalized intersections was combined by replacing an unsignalized intersection with an equivalent number of driveway access points. To establish this equivalency, a statistical safety impact model was estimated multiple times with assumed different intersection/driveway weights until the best performing model was found.

The table below shows the model goodness of fit in terms of adjusted R square for the crash equations. A higher Adjusted R indicates better fitness of the crash model. Given three median treatments and three severity levels, there are 9 models as shown in Table B.1. For example, *KA_D* represents KA severity model for non-traversable median treatment. Comparing the average model fitness, the overall model fitness is best when the weight is set to be 5.

Table B.1 Comparison of model fitness with different weights of unsignalized intersections

Model	**Adjusted R square for Crash Equation**						
	Weight = 1	Weight = 2	Weight = 3	Weight = 4	Weight = 5	Weight = 6	Weight = 7
KA_D	0.065	0.090	0.106	0.116	0.122	0.125	0.128
BC_D	0.302	0.308	0.306	0.302	0.299	0.296	0.293
PD_D	0.195	0.233	0.253	0.263	0.268	0.271	0.272
KA_T	0.041	0.058	0.071	0.080	0.086	0.089	0.090
BC_T	0.117	0.124	0.129	0.134	0.136	0.138	0.139
PD_T	0.216	0.247	0.265	0.272	0.272	0.269	0.264
KA_U	0.432	0.460	0.471	0.470	0.462	0.451	0.441
BC_U	0.441	0.452	0.460	0.464	0.465	0.465	0.464
PD_U	0.666	0.693	0.712	0.722	0.724	0.723	0.720
Average	0.275	0.296	0.308	0.314	0.315	0.314	0.312

APPENDIX C. MODEL

C.1 Undivided KA Crash

```
systemfit results
method: OLS

        N DF      SSR detRCov   OLS-R2 McElroy-R2
system 66 58 729.123 12.7796 0.399611   0.452747

        N DF      SSR       MSE     RMSE       R2   Adj R2
Crash  33 29  15.1613  0.522803 0.723051 0.512253 0.461797
SpdLmt 33 29 713.9614 24.619360 4.961790 0.396652 0.334237

The covariance matrix of the residuals
           Crash    SpdLmt
Crash   0.522803 -0.302468
SpdLmt -0.302468 24.619360

The correlations of the residuals
            Crash     SpdLmt
Crash   1.0000000 -0.0843087
SpdLmt -0.0843087  1.0000000


OLS estimates for 'Crash' (equation 1)
Model Formula: logKA ~ SpdLimit + logAADT + AccDen

                Estimate   Std. Error  t value  Pr(>|t|)
(Intercept) -13.36433697   3.93355573 -3.39752 0.0019933 **
SpdLimit     -0.01317646   0.02534550 -0.51987 0.6070975
logAADT       1.61355930   0.42054297  3.83685 0.0006219 ***
AccDen        0.01122632   0.00373398  3.00653 0.0054103 **
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 0.723051 on 29 degrees of freedom
Number of observations: 33 Degrees of Freedom: 29
SSR: 15.161294 MSE: 0.522803 Root MSE: 0.723051
Multiple R-Squared: 0.512253 Adjusted R-Squared: 0.461797


OLS estimates for 'SpdLmt' (equation 2)
Model Formula: SpdLimit ~ logKA + AccDen + loglength

              Estimate Std. Error  t value   Pr(>|t|)
(Intercept) 49.8882468  3.4762466 14.35118 1.0436e-14 ***
logKA       -0.4724905  1.0759860 -0.43912  0.6638269
AccDen      -0.0772015  0.0251491 -3.06975  0.0046173 **
loglength    3.6486718  1.5992156  2.28154  0.0300423 *
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 4.96179 on 29 degrees of freedom
Number of observations: 33 Degrees of Freedom: 29
SSR: 713.961432 MSE: 24.61936 Root MSE: 4.96179
Multiple R-Squared: 0.396652 Adjusted R-Squared: 0.334237
```

C.2 Undivided BC Crash

```
systemfit results
method: OLS

        N DF     SSR detRCov   OLS-R2 McElroy-R2
system 66 58 589.653 9.64256 0.514481   0.602301

        N DF      SSR       MSE     RMSE       R2   Adj R2
Crash  33 29  15.0918  0.520408 0.721393 0.515463 0.465338
SpdLmt 33 29 574.5614 19.812461 4.451119 0.514455 0.464226

The covariance matrix of the residuals
          Crash    SpdLmt
Crash  0.520408  0.817314
SpdLmt 0.817314 19.812461

The correlations of the residuals
          Crash   SpdLmt
Crash  1.000000 0.254535
SpdLmt 0.254535 1.000000


OLS estimates for 'Crash' (equation 1)
Model Formula: logBC ~ SpdLimit + logAADT + AccDen

               Estimate  Std. Error  t value  Pr(>|t|)
(Intercept) -6.66648488  3.92453530 -1.69867 0.1000874
SpdLimit    -0.07711009  0.02528738 -3.04935 0.0048602 **
logAADT      1.23652827  0.41957858  2.94707 0.0062728 **
AccDen       0.00611078  0.00372542  1.64029 0.1117479
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.721393 on 29 degrees of freedom
Number of observations: 33 Degrees of Freedom: 29
SSR: 15.091838 MSE: 0.520408 Root MSE: 0.721393
Multiple R-Squared: 0.515463 Adjusted R-Squared: 0.465338


OLS estimates for 'SpdLmt' (equation 2)
Model Formula: SpdLimit ~ logBC + AccDen + loglength

              Estimate Std. Error  t value Pr(>|t|)
(Intercept) 53.5019757  3.0369184 17.61719  < 2e-16 ***
logBC       -2.5114164  0.9310747 -2.69733 0.011523 *
AccDen      -0.0520713  0.0224476 -2.31969 0.027601 *
loglength    3.7465068  1.3871427  2.70088 0.011426 *
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 4.451119 on 29 degrees of freedom
Number of observations: 33 Degrees of Freedom: 29
SSR: 574.561369 MSE: 19.812461 Root MSE: 4.451119
Multiple R-Squared: 0.514455 Adjusted R-Squared: 0.464226
```

C.3 Undivided PD Crash

```
systemfit results
method: OLS

        N DF     SSR detRCov   OLS-R2 McElroy-R2
system 66 58 714.026 6.08524 0.411412   0.679304

        N DF       SSR       MSE     RMSE       R2   Adj R2
Crash  33 29   7.44311  0.256659 0.506615 0.750095 0.724243
SpdLmt 33 29 706.58261 24.364918 4.936083 0.402888 0.341118

The covariance matrix of the residuals
          Crash    SpdLmt
Crash  0.256659  0.410163
SpdLmt 0.410163 24.364918

The correlations of the residuals
         Crash  SpdLmt
Crash  1.00000 0.16402
SpdLmt 0.16402 1.00000


OLS estimates for 'Crash' (equation 1)
Model Formula: logPD ~ SpdLimit + logAADT + AccDen

                Estimate   Std. Error  t value   Pr(>|t|)
(Intercept) -12.61490410   2.75609552 -4.57709 8.2038e-05 ***
SpdLimit     -0.05356500   0.01775865 -3.01628 0.00528009 **
logAADT       1.92767258   0.29465874  6.54205 3.6424e-07 ***
AccDen        0.00959470   0.00261626  3.66733 0.00097912 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.506615 on 29 degrees of freedom
Number of observations: 33 Degrees of Freedom: 29
SSR: 7.443106 MSE: 0.256659 Root MSE: 0.506615
Multiple R-Squared: 0.750095 Adjusted R-Squared: 0.724243


OLS estimates for 'SpdLmt' (equation 2)
Model Formula: SpdLimit ~ logPD + AccDen + loglength

              Estimate Std. Error  t value  Pr(>|t|)
(Intercept) 51.2634911  4.2666674 12.01488 8.793e-13 ***
logPD       -0.8185215  1.1602484 -0.70547  0.486146
AccDen      -0.0711813  0.0271138 -2.62528  0.013675 *
loglength    3.1845358  1.5835292  2.01104  0.053699 .
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 4.936083 on 29 degrees of freedom
Number of observations: 33 Degrees of Freedom: 29
SSR: 706.582608 MSE: 24.364918 Root MSE: 4.936083
Multiple R-Squared: 0.402888 Adjusted R-Squared: 0.341118
```

C.4 Two-Way Left-Turn Lane KA Crash

```
systemfit results
method: OLS

         N  DF     SSR detRCov   OLS-R2 McElroy-R2
system 172 164 4127.01 70.2186 0.041568   0.080477

        N DF      SSR      MSE    RMSE       R2   Adj R2
Crash  86 82  117.869  1.43742 1.19893 0.117878 0.085606
SpdLmt 86 82 4009.141 48.89197 6.99228 0.039124 0.003970

The covariance matrix of the residuals
           Crash    SpdLmt
Crash   1.437423 -0.244671
SpdLmt -0.244671 48.891969

The correlations of the residuals
            Crash     SpdLmt
Crash   1.0000000 -0.0291858
SpdLmt -0.0291858  1.0000000


OLS estimates for 'Crash' (equation 1)
Model Formula: logKA ~ SpdLimit + logAADT + AccDen

               Estimate  Std. Error  t value Pr(>|t|)
(Intercept) -4.67218604  3.24282926 -1.44077 0.153456
SpdLimit     0.00651566  0.01882081  0.34619 0.730083
logAADT      0.57303627  0.31989636  1.79132 0.076932 .
AccDen       0.00982307  0.00374671  2.62178 0.010424 *
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 1.198926 on 82 degrees of freedom
Number of observations: 86 Degrees of Freedom: 82
SSR: 117.868691 MSE: 1.437423 Root MSE: 1.198926
Multiple R-Squared: 0.117878 Adjusted R-Squared: 0.085606


OLS estimates for 'SpdLmt' (equation 2)
Model Formula: SpdLimit ~ logKA + AccDen + loglength

              Estimate Std. Error  t value Pr(>|t|)
(Intercept) 44.1274964  2.9229179 15.09707  < 2e-16 ***
logKA        0.0422567  0.6432726  0.06569  0.94778
AccDen      -0.0372640  0.0227253 -1.63976  0.10489
loglength    1.3064028  1.2605566  1.03637  0.30308
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 6.992279 on 82 degrees of freedom
Number of observations: 86 Degrees of Freedom: 82
SSR: 4009.141429 MSE: 48.891969 Root MSE: 6.992279
Multiple R-Squared: 0.039124 Adjusted R-Squared: 0.00397
```

C.5 Two-Way Left-Turn Lane BC Crash

```
systemfit results
method: OLS

        N  DF     SSR detRCov   OLS-R2 McElroy-R2
system 172 164 3864.07 73.9971 0.110001   0.230679

        N DF      SSR      MSE    RMSE       R2   Adj R2
Crash  86 82  141.014  1.71969 1.31137 0.166930 0.136452
SpdLmt 86 82 3723.054 45.40309 6.73818 0.107691 0.075046

The covariance matrix of the residuals
        Crash   SpdLmt
Crash  1.71969  2.02038
SpdLmt 2.02038 45.40309

The correlations of the residuals
          Crash   SpdLmt
Crash  1.000000 0.228647
SpdLmt 0.228647 1.000000


OLS estimates for 'Crash' (equation 1)
Model Formula: logBC ~ SpdLimit + logAADT + AccDen

               Estimate  Std. Error  t value Pr(>|t|)
(Intercept) -4.91067657  3.54696125 -1.38447 0.169969
SpdLimit    -0.04595557  0.02058594 -2.23238 0.028317 *
logAADT      0.84435453  0.34989816  2.41314 0.018045 *
AccDen       0.00680919  0.00409810  1.66155 0.100423
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 1.311368 on 82 degrees of freedom
Number of observations: 86 Degrees of Freedom: 82
SSR: 141.014309 MSE: 1.719687 Root MSE: 1.311368
Multiple R-Squared: 0.16693 Adjusted R-Squared: 0.136452


OLS estimates for 'SpdLmt' (equation 2)
Model Formula: SpdLimit ~ logBC + AccDen + loglength

              Estimate Std. Error  t value Pr(>|t|)
(Intercept) 46.9248195  2.8025660 16.74352  < 2e-16 ***
logBC       -1.3553023  0.5397207 -2.51112 0.013999 *
AccDen      -0.0264492  0.0216153 -1.22363 0.224596
loglength    1.8336981  1.2098558  1.51563 0.133458
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 6.738182 on 82 degrees of freedom
Number of observations: 86 Degrees of Freedom: 82
SSR: 3723.053599 MSE: 45.403093 Root MSE: 6.738182
Multiple R-Squared: 0.107691 Adjusted R-Squared: 0.075046
```

C.6 Two-Way Left-Turn Lane PD Crash

```
systemfit results
method: OLS

         N  DF     SSR detRCov   OLS-R2 McElroy-R2
system 172 164 4008.22 43.7549 0.063587   0.222745

        N DF       SSR       MSE     RMSE       R2   Adj R2
Crash  86 82   75.8573  0.925089 0.961816 0.297717 0.272024
SpdLmt 86 82 3932.3644 47.955663 6.925003 0.057526 0.023045

The covariance matrix of the residuals
          Crash    SpdLmt
Crash  0.925089  0.779986
SpdLmt 0.779986 47.955663

The correlations of the residuals
          Crash   SpdLmt
Crash  1.000000 0.117105
SpdLmt 0.117105 1.000000


OLS estimates for 'Crash' (equation 1)
Model Formula: logPD ~ SpdLimit + logAADT + AccDen

               Estimate  Std. Error  t value   Pr(>|t|)
(Intercept) -3.04617989  2.60149851 -1.17093  0.2450173
SpdLimit    -0.01617860  0.01509864 -1.07153  0.2870760
logAADT      0.71194683  0.25663081  2.77421  0.0068504 **
AccDen       0.01372059  0.00300573  4.56481 1.7382e-05 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.961816 on 82 degrees of freedom
Number of observations: 86 Degrees of Freedom: 82
SSR: 75.857313 MSE: 0.925089 Root MSE: 0.961816
Multiple R-Squared: 0.297717 Adjusted R-Squared: 0.272024


OLS estimates for 'SpdLmt' (equation 2)
Model Formula: SpdLimit ~ logPD + AccDen + loglength

              Estimate Std. Error  t value Pr(>|t|)
(Intercept) 47.5423705  3.7414653 12.70689  < 2e-16 ***
logPD       -0.9610101  0.7584663 -1.26704  0.20873
AccDen      -0.0231264  0.0243571 -0.94947  0.34517
loglength    1.4856128  1.2324184  1.20545  0.23150
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 6.925003 on 82 degrees of freedom
Number of observations: 86 Degrees of Freedom: 82
SSR: 3932.364375 MSE: 47.955663 Root MSE: 6.925003
Multiple R-Squared: 0.057526 Adjusted R-Squared: 0.023045
```

C.7 Non-Traversable KA Crash

```
systemfit results
method: OLS

        N  DF     SSR detRCov   OLS-R2 McElroy-R2
system 162 154 1995.55 49.8612 0.247058   0.250113

        N DF      SSR      MSE    RMSE       R2   Adj R2
Crash  81 77  164.685  2.13876 1.46245 0.154528 0.121587
SpdLmt 81 77 1830.868 23.77750 4.87622 0.254398 0.225348

The covariance matrix of the residuals
          Crash    SpdLmt
Crash  2.138760  0.996606
SpdLmt 0.996606 23.777504

The correlations of the residuals
          Crash   SpdLmt
Crash  1.000000 0.139752
SpdLmt 0.139752 1.000000


OLS estimates for 'Crash' (equation 1)
Model Formula: logKA ~ SpdLimit + logAADT + AccDen

               Estimate  Std. Error  t value  Pr(>|t|)
(Intercept)  1.04024773  4.36181399  0.23849 0.8121349
SpdLimit    -0.04431748  0.03211343 -1.38003 0.1715714
logAADT      0.20937156  0.43144062  0.48528 0.6288523
AccDen       0.01114922  0.00416784  2.67506 0.0091223 **
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 1.46245 on 77 degrees of freedom
Number of observations: 81 Degrees of Freedom: 77
SSR: 164.684543 MSE: 2.13876 Root MSE: 1.46245
Multiple R-Squared: 0.154528 Adjusted R-Squared: 0.121587


OLS estimates for 'SpdLmt' (equation 2)
Model Formula: SpdLimit ~ logKA + AccDen + loglength

              Estimate Std. Error  t value   Pr(>|t|)
(Intercept) 52.1278551  1.3738345 37.94333 < 2.22e-16 ***
logKA       -0.5301460  0.3752277 -1.41286  0.1617250
AccDen      -0.0336541  0.0138827 -2.42417  0.0176886 *
loglength    2.3129816  0.6910692  3.34696  0.0012659 **
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 4.876218 on 77 degrees of freedom
Number of observations: 81 Degrees of Freedom: 77
SSR: 1830.867791 MSE: 23.777504 Root MSE: 4.876218
Multiple R-Squared: 0.254398 Adjusted R-Squared: 0.225348
```

C.8 Non-Traversable BC Crash

```
systemfit results
method: OLS

        N  DF     SSR detRCov   OLS-R2 McElroy-R2
system 162 154 1905.14 37.7048 0.280119   0.347611

        N DF      SSR      MSE    RMSE       R2   Adj R2
Crash  81 77  128.882  1.67379 1.29375 0.324926 0.298624
SpdLmt 81 77 1776.263 23.06835 4.80295 0.276635 0.248452

The covariance matrix of the residuals
          Crash    SpdLmt
Crash  1.673790  0.952238
SpdLmt 0.952238 23.068351

The correlations of the residuals
          Crash   SpdLmt
Crash  1.000000 0.153245
SpdLmt 0.153245 1.000000


OLS estimates for 'Crash' (equation 1)
Model Formula: logBC ~ SpdLimit + logAADT + AccDen

                Estimate   Std. Error  t value   Pr(>|t|)
(Intercept) -10.53681641   3.85866005 -2.73069 0.00783127 **
SpdLimit     -0.06856782   0.02840901 -2.41359 0.01817222 *
logAADT       1.49251347   0.38167209  3.91046 0.00019699 ***
AccDen        0.01025543   0.00368706  2.78146 0.00680114 **
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 1.29375 on 77 degrees of freedom
Number of observations: 81 Degrees of Freedom: 77
SSR: 128.881801 MSE: 1.67379 Root MSE: 1.29375
Multiple R-Squared: 0.324926 Adjusted R-Squared: 0.298624


OLS estimates for 'SpdLmt' (equation 2)
Model Formula: SpdLimit ~ logBC + AccDen + loglength

              Estimate Std. Error  t value   Pr(>|t|)
(Intercept) 52.8288638  1.4274893 37.00824 < 2.22e-16 ***
logBC       -0.8049136  0.3826576 -2.10348 0.03868909 *
AccDen      -0.0284996  0.0140149 -2.03353 0.04544494 *
loglength    2.4705948  0.6849294  3.60708 0.00054795 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 4.802952 on 77 degrees of freedom
Number of observations: 81 Degrees of Freedom: 77
SSR: 1776.263003 MSE: 23.068351 Root MSE: 4.802952
Multiple R-Squared: 0.276635 Adjusted R-Squared: 0.248452
```

C.9 Non-Traversable PD Crash

```
systemfit results
method: OLS

         N  DF     SSR detRCov   OLS-R2 McElroy-R2
system 162 154 1912.05 41.3557 0.281513    0.36434

        N DF     SSR      MSE    RMSE       R2   Adj R2
Crash  81 77  144.90  1.88181 1.37179 0.295440 0.267989
SpdLmt 81 77 1767.15 22.94998 4.79061 0.280347 0.252308

The covariance matrix of the residuals
         Crash   SpdLmt
Crash  1.88181  1.35348
SpdLmt 1.35348 22.94998

The correlations of the residuals
          Crash   SpdLmt
Crash  1.000000 0.205955
SpdLmt 0.205955 1.000000


OLS estimates for 'Crash' (equation 1)
Model Formula: logPD ~ SpdLimit + logAADT + AccDen

               Estimate  Std. Error  t value   Pr(>|t|)
(Intercept)  0.15064515  4.09142269  0.03682 0.97072402
SpdLimit    -0.06750020  0.03012270 -2.24084 0.02791819 *
logAADT      0.60951860  0.40469537  1.50612 0.13612869
AccDen       0.01474076  0.00390948  3.77052 0.00031768 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 1.371792 on 77 degrees of freedom
Number of observations: 81 Degrees of Freedom: 77
SSR: 144.899623 MSE: 1.881813 Root MSE: 1.371792
Multiple R-Squared: 0.29544 Adjusted R-Squared: 0.267989


OLS estimates for 'SpdLmt' (equation 2)
Model Formula: SpdLimit ~ logPD + AccDen + loglength

              Estimate Std. Error  t value   Pr(>|t|)
(Intercept) 54.2161724  1.7637077 30.73989 < 2.22e-16 ***
logPD       -0.8425573  0.3827988 -2.20104 0.03072885 *
AccDen      -0.0251631  0.0145541 -1.72893 0.08782844 .
loglength    2.3458232  0.6791253  3.45418 0.00090053 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 4.790614 on 77 degrees of freedom
Number of observations: 81 Degrees of Freedom: 77
SSR: 1767.148662 MSE: 22.949983 Root MSE: 4.790614
Multiple R-Squared: 0.280347 Adjusted R-Squared: 0.252308
```

APPENDIX D. INDIANA CRASH FREQUENCIES

The estimates are obtained with the RoadHAT tool. These values should be considered as a reference. They have been obtained based on the entire state data, but the median treatments information was not available while the segments definition is based on default distances to end intersections.

Table D.1 RoadHAT-estimated annual crash number (1-mile urban multilane segment)

AADT	Severity	Intersection Density									
		1	2	3	4	5	6	7	8	9	10
2,000	KA	0.039	0.041	0.042	0.044	0.046	0.047	0.049	0.051	0.053	0.055
	BC	0.057	0.059	0.061	0.063	0.066	0.068	0.070	0.073	0.076	0.078
	PD	0.322	0.334	0.346	0.358	0.371	0.385	0.399	0.413	0.428	0.444
4,000	KA	0.080	0.083	0.086	0.089	0.093	0.096	0.100	0.103	0.107	0.111
	BC	0.120	0.124	0.129	0.133	0.138	0.143	0.148	0.154	0.159	0.165
	PD	0.705	0.730	0.757	0.784	0.813	0.842	0.873	0.905	0.938	0.972
6,000	KA	0.121	0.125	0.130	0.135	0.140	0.145	0.151	0.156	0.162	0.168
	BC	0.186	0.192	0.199	0.206	0.214	0.221	0.229	0.238	0.246	0.255
	PD	1.114	1.155	1.197	1.240	1.285	1.332	1.380	1.431	1.483	1.537
8,000	KA	0.162	0.168	0.175	0.181	0.188	0.195	0.202	0.210	0.217	0.225
	BC	0.253	0.262	0.271	0.281	0.291	0.302	0.313	0.324	0.335	0.348
	PD	1.543	1.599	1.657	1.717	1.779	1.844	1.911	1.980	2.052	2.127
10,000	KA	0.204	0.211	0.219	0.227	0.236	0.245	0.254	0.263	0.273	0.283
	BC	0.321	0.333	0.345	0.357	0.370	0.383	0.397	0.412	0.426	0.442
	PD	1.985	2.057	2.132	2.210	2.290	2.373	2.459	2.549	2.641	2.737
12,000	KA	0.245	0.255	0.264	0.274	0.284	0.295	0.306	0.317	0.329	0.341
	BC	0.391	0.405	0.420	0.435	0.450	0.466	0.483	0.501	0.519	0.537
	PD	2.440	2.528	2.620	2.715	2.814	2.916	3.022	3.132	3.246	3.364
14,000	KA	0.287	0.298	0.309	0.320	0.332	0.345	0.358	0.371	0.385	0.399
	BC	0.461	0.478	0.495	0.513	0.531	0.551	0.570	0.591	0.612	0.634
	PD	2.904	3.009	3.119	3.232	3.350	3.471	3.597	3.728	3.864	4.004
16,000	KA	0.329	0.341	0.354	0.367	0.381	0.395	0.410	0.425	0.441	0.457
	BC	0.533	0.552	0.572	0.592	0.613	0.635	0.658	0.682	0.707	0.732
	PD	3.377	3.500	3.627	3.759	3.895	4.037	4.184	4.336	4.493	4.657
18,000	KA	0.371	0.385	0.399	0.414	0.430	0.446	0.462	0.479	0.497	0.516
	BC	0.604	0.626	0.649	0.672	0.696	0.721	0.747	0.774	0.802	0.831
	PD	3.858	3.998	4.143	4.294	4.450	4.612	4.779	4.953	5.133	5.320
20,000	KA	0.413	0.429	0.445	0.461	0.478	0.496	0.515	0.534	0.554	0.574
	BC	0.677	0.701	0.726	0.753	0.780	0.808	0.837	0.867	0.898	0.930
	PD	4.346	4.504	4.668	4.837	5.013	5.195	5.384	5.580	5.782	5.993
22,000	KA	0.455	0.472	0.490	0.508	0.527	0.547	0.567	0.588	0.610	0.633
	BC	0.750	0.777	0.805	0.834	0.864	0.895	0.927	0.960	0.995	1.031
	PD	4.840	5.016	5.199	5.387	5.583	5.786	5.996	6.214	6.440	6.674
24,000	KA	0.498	0.516	0.535	0.555	0.576	0.598	0.620	0.643	0.667	0.692

AADT	Severity	Intersection Density									
		1	2	3	4	5	6	7	8	9	10
	BC	0.823	0.853	0.884	0.915	0.948	0.983	1.018	1.055	1.092	1.132
	PD	5.341	5.535	5.736	5.944	6.160	6.384	6.616	6.857	7.106	7.364
26,000	KA	0.540	0.560	0.581	0.603	0.625	0.648	0.673	0.698	0.723	0.750
	BC	0.897	0.930	0.963	0.998	1.034	1.071	1.109	1.149	1.191	1.233
	PD	5.846	6.059	6.279	6.507	6.744	6.989	7.243	7.506	7.779	8.061
28,000	KA	0.583	0.604	0.627	0.650	0.674	0.699	0.725	0.752	0.780	0.809
	BC	0.972	1.007	1.043	1.080	1.119	1.160	1.201	1.245	1.289	1.336
	PD	6.357	6.588	6.828	7.076	7.333	7.599	7.876	8.162	8.458	8.766
30,000	KA	0.625	0.648	0.672	0.697	0.723	0.750	0.778	0.807	0.837	0.868
	BC	1.047	1.084	1.123	1.164	1.205	1.249	1.294	1.340	1.389	1.438
	PD	6.873	7.123	7.382	7.650	7.928	8.216	8.514	8.824	9.145	9.477
32,000	KA	0.668	0.692	0.718	0.745	0.773	0.801	0.831	0.862	0.894	0.927
	BC	1.122	1.162	1.204	1.247	1.292	1.339	1.387	1.437	1.488	1.542
	PD	7.393	7.662	7.940	8.229	8.528	8.838	9.159	9.492	9.837	10.194
34,000	KA	0.710	0.737	0.764	0.792	0.822	0.852	0.884	0.917	0.951	0.987
	BC	1.197	1.240	1.285	1.331	1.379	1.429	1.480	1.533	1.588	1.646
	PD	7.917	8.205	8.503	8.812	9.133	9.465	9.809	10.165	10.534	10.917
36,000	KA	0.753	0.781	0.810	0.840	0.871	0.904	0.937	0.972	1.008	1.046
	BC	1.273	1.319	1.366	1.415	1.466	1.519	1.574	1.630	1.689	1.750
	PD	8.446	8.753	9.071	9.401	9.742	10.096	10.463	10.843	11.237	11.646
38,000	KA	0.795	0.825	0.856	0.888	0.921	0.955	0.990	1.027	1.066	1.105
	BC	1.349	1.398	1.448	1.500	1.554	1.610	1.668	1.728	1.790	1.855
	PD	8.978	9.305	9.643	9.993	10.356	10.733	11.123	11.527	11.946	12.380
40,000	KA	0.838	0.869	0.902	0.935	0.970	1.006	1.044	1.083	1.123	1.165
	BC	1.426	1.477	1.530	1.585	1.642	1.701	1.762	1.826	1.892	1.960
	PD	9.514	9.860	10.218	10.590	10.974	11.373	11.787	12.215	12.659	13.119
42,000	KA	0.881	0.914	0.948	0.983	1.020	1.058	1.097	1.138	1.180	1.224
	BC	1.502	1.557	1.613	1.671	1.731	1.793	1.857	1.924	1.993	2.065
	PD	10.054	10.419	10.798	11.190	11.597	12.018	12.455	12.908	13.377	13.863
44,000	KA	0.924	0.958	0.994	1.031	1.069	1.109	1.150	1.193	1.237	1.284
	BC	1.580	1.636	1.695	1.756	1.819	1.885	1.953	2.023	2.096	2.171
	PD	10.597	10.982	11.381	11.794	12.223	12.667	13.127	13.604	14.099	14.611
46,000	KA	0.967	1.003	1.040	1.079	1.119	1.160	1.204	1.248	1.295	1.343
	BC	1.657	1.716	1.778	1.842	1.908	1.977	2.048	2.122	2.198	2.277
	PD	11.143	11.548	11.967	12.402	12.853	13.320	13.804	14.306	14.825	15.364
48,000	KA	1.010	1.047	1.086	1.127	1.168	1.212	1.257	1.304	1.352	1.403
	BC	1.734	1.797	1.861	1.928	1.998	2.070	2.144	2.221	2.301	2.384
	PD	11.692	12.117	12.557	13.013	13.486	13.976	14.484	15.011	15.556	16.121
50,000	KA	1.053	1.092	1.132	1.174	1.218	1.264	1.311	1.359	1.410	1.462
	BC	1.812	1.877	1.945	2.015	2.087	2.162	2.240	2.321	2.404	2.491
	PD	12.244	12.689	13.150	13.628	14.123	14.636	15.168	15.720	16.291	16.883

The average comprehensive crash cost (in 1,000 USD) by severity and speed limit presented in Table 5.3. and the Table D.1 were used to obtain expected annual crash cost (in 1,000 USD) for specific speed limit, AADT and access point density. The expected annual crash cost (in 1,000 USD) for the speeds 30–35 mph, 40–45 mph and 50–55 mph are represented in Tables D.2, D.3, and D.4.

The obtained Table D.1 using RoadHAT tool mentions intersection density (unsignalized intersection density within a segment), however it has been found in this study that each unsignalized intersection (counted separately on two directions) is equivalent to five driveways (weightage explained in Appendix 0). Thus here, general access point density is calculated by multiplying the intersection density by the equivalency per direction and then doubling the result to account for both directions. This equivalency is used in Table D.2 to Table D.4 and intersection density is expressed as general access point density.

Table D.2 Expected annual crash cost (1,000 USD) for 30–35 mph

AADT	**General Access Point Density**									
	10	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**
2,000	99	103	107	111	115	119	123	128	133	137
4,000	205	213	220	229	237	246	255	264	274	284
6,000	314	325	337	350	363	376	390	404	419	434
8,000	424	440	456	473	490	508	527	547	567	588
10,000	536	556	577	598	620	643	666	691	716	743
12,000	649	673	698	724	750	778	807	836	867	899
14,000	764	792	821	851	882	915	949	983	1,020	1,057
16,000	879	911	944	979	1,015	1,053	1,091	1,132	1,173	1,216
18,000	994	1,031	1,069	1,108	1,149	1,191	1,235	1,281	1,328	1,377
20,000	1,111	1,152	1,194	1,238	1,284	1,331	1,380	1,431	1,483	1,538
22,000	1,228	1,273	1,320	1,368	1,419	1,471	1,525	1,581	1,639	1,700
24,000	1,345	1,395	1,446	1,499	1,555	1,612	1,671	1,733	1,797	1,863
26,000	1,464	1,517	1,573	1631	1,691	1,753	1,818	1,885	1,954	2,026
28,000	1,582	1,640	1,701	1,763	1,828	1,896	1,965	2,038	2,113	2,190
30,000	1,701	1,764	1,829	1,896	1,966	2,038	2,113	2,191	2,272	2,355
32000	1,821	1,888	1,957	2,029	2,104	2,181	2,262	2,345	2,431	2,521
34,000	1,941	2,012	2,086	2,163	2,242	2,325	2,411	2,499	2,591	2,687
36,000	2,061	2,137	2,215	2,297	2,381	2,469	2,560	2,654	2,752	2,853
38,000	2,182	2,,262	2,345	2,431	2,521	2,614	2,710	2,809	2,913	3,020
40,000	2,303	2,387	2,475	2,566	2,661	2,759	2,860	2,965	3,074	3,188
42,000	2,424	2,513	2,606	2,701	2,801	2,904	3,011	3,122	3,236	3,355
44,000	2,546	2,639	2,736	2,837	2,941	3,050	3,162	3,278	3,399	3,524
46,000	2,667	2,766	2,867	2,973	3,082	3,196	3,313	3,435	3,562	3,693
48,000	2,790	2,892	2,999	3,109	3,223	3,342	3,465	3,593	3,725	3,862
50,000	2,912	3,019	3,130	3,246	3,365	3,489	3,617	3,750	3,888	4,031

Table D.3 Expected annual crash cost (1,000 USD) for 40–45 mph

AADT	General Access Point Density									
	10	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**
2,000	108	112	116	120	124	129	134	139	144	149
4,000	222	230	239	247	257	266	276	286	297	308
6,000	339	352	365	378	392	406	421	437	453	470
8,000	458	475	493	511	530	549	569	590	612	635
10,000	579	600	622	645	669	694	719	746	773	802
12,000	700	726	753	781	810	839	870	902	936	970
14,000	823	854	885	918	951	986	1,023	1,061	1,100	1,140
16,000	947	982	1,018	1,055	1,094	1,135	1,176	1,220	1,265	1,311
18,000	1,071	1,111	1,151	1,194	1,238	1,283	1,331	1,380	1,431	1,483
20,000	1,196	1,240	1,286	1,333	1,382	1,433	1,486	1,541	1,598	1,656
22,000	1,322	1,370	1,421	1,473	1,527	1,584	1,642	1,703	1,765	1,830
24,000	1,448	1,501	1,557	1,614	1,673	1,735	1,799	1,865	1,934	2,005
26,000	1,575	1,633	1,693	1,755	1820	1,887	1,956	2,028	2,103	2,181
28,000	1,702	1,764	1,829	1,897	1,967	2,039	2,114	2,192	2,273	2,357
30,000	1,829	1,897	1,967	2,039	2,114	2,192	2,273	2,357	2,443	2,533
32,000	1,957	2,030	2,104	2,182	2,262	2,346	2,432	2,522	2,615	2,711
34,000	2086	2,163	2,242	2,325	2,411	2,500	2,592	2,687	2,786	2,889
36,000	2,215	2,296	2,381	2469	2,560	2,654	2,752	2,853	2,958	3,067
38,000	2,344	2,430	2,520	2,613	2,709	2,809	2,912	3,020	3,131	3,246
40,000	2,474	2,565	2,659	2,757	2,859	2,964	3,073	3,186	3,304	3,425
42,000	2,604	2,699	2,799	2,902	3,009	3,120	3,235	3,354	3,477	3,605
44,000	2,734	2,834	2,939	3,047	3,159	3,276	3,396	3,521	3,651	3,786
46,000	2,864	2,970	3,079	3,193	3,310	3,432	3,558	3,690	3,825	3,966
48,000	2,995	3,105	3,220	3,338	3,461	3,589	3,721	3,858	4,000	4,147
50,000	3,126	3,241	3,361	3,484	3,613	3,746	3,884	4,027	4,175	4,329

Table D.4 Expected annual crash cost (1,000 USD) for 50–55 mph

AADT	**General Access Point Density**									
	10	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**
2,000	130	134	139	144	150	155	161	167	173	180
4,000	266	275	286	296	307	319	330	343	355	368
6,000	405	419	435	451	468	485	503	522	541	561
8,000	545	565	586	608	630	654	678	703	729	756
10,000	687	713	739	766	795	824	855	886	919	953
12,000	831	861	893	926	960	996	1,033	1,071	1,110	1,151
14,000	975	1,011	1,048	1,087	1,127	1,169	1,212	1,257	1,303	1,351
16,000	1,120	1,161	1,204	1,248	1,295	1,342	1,392	1,443	1,497	1,552
18,000	1,265	1,312	1,361	1,411	1,463	1,517	1,573	1,631	1,692	1,754
20,000	1,412	1,464	1,518	1,574	1,632	1,693	1,755	1,820	1,887	1,957
22,000	1,559	1,616	1,676	1,738	1,802	1,869	1,938	2,009	2,084	2,161
24,000	1,706	1,769	1,835	1,902	1,973	2,045	2,121	2,199	2,281	2,365
26,000	1,854	1,923	1,994	2,067	2,144	2,223	2,305	2,390	2,478	2,570
28,000	2,003	2,077	2,153	2,233	2,315	2,401	2,490	2,581	2,677	2,776
30,000	2,151	2,231	2,313	2,399	2,487	2,579	2,675	2,773	2,876	2,982
32,000	2,301	2,386	2,474	2,565	2,660	2,758	2,860	2,966	3,075	3,189
34,000	2,450	2,541	2,635	2,732	2,833	2,938	3,046	3,159	3,275	3,396
36,000	2,600	2,696	2,796	2,899	3,006	3,117	3,233	3,352	3,476	3,604
38,000	2,751	2,852	2,958	3,067	3,180	3,298	3,419	3,546	3,677	3,813
40,000	2,901	3,009	3,120	3,235	3,354	3,478	3,607	3,740	3,878	4,021
42,000	3,052	3,165	3,282	3,403	3,529	3,659	3,794	3,935	4,080	4,231
44,000	3,204	3,322	3,445	3,572	3,704	3,841	3,982	4,130	4,282	4,440
46,000	3,355	3,479	3,608	3,741	3,879	4,022	4,171	4,325	4,485	4,650
48,000	3,507	3,637	3,771	3,910	4,055	4,204	4,360	4,521	4,688	4,861
50,000	3,659	3,794	3,934	4,080	4,230	4,387	4,549	4,717	4,891	5,071

APPENDIX E. SAMPLE DISTRIBUTION

Because the crash cost tables presented in the report (Table 6.1, Table 6.2, Table 6.3, Table 6.4, Table 6.5, and Table 6.6) are uniformly estimated, the maximum AADT and maximum access point density are the maximum values observed in the entire sample data. However, certain AADT or access point density might not be realistic under different speed limits and median treatment, for example, high AADT values on low-speed-limit segments with undivided median. To help users identify the potential risk of using estimated costs with limited data, the distribution of sample data across AADT and access point density by speed limit and median types are provided in this appendix. The ranges that are inside the convex of available samples are believed to be reliable estimates with interpolation of the data, while ranges that are outside the convex might be questionable (extrapolation of the data). Because the operational conditions are similar for segments with close speed limits, three speed limit groups (Group 1: 30 or 35 mph; Group 2: 40 or 45 mph; Group 3: 50 or 55 mph) are used for the sample distribution summary.

The distributions of samples were summarized by speed limits groups, median types (undivided, TWLTL, non-traversable), density of access points (10, 20, …, 100) and AADT (2,000, 4,000, …, 50,000) in the tables below. In the tables presented, the average annual daily traffic values represent the upper bounds, for example, 2,000 means the range of [0, 2,000); the count values in the cells represent the number of samples. Among the provided sample distribution tables, Table E.3 (speed limit = 30 or 35 mph; median type = non-traversable) and Table E.7 (speed limit = 50 or 55 mph; median type = undivided) have very limited samples, only the cells that have samples are considered as supported by observed data. The cost tables provided in the report have been updated based on the following tables. If the estimated costs are outside the convex ranges of the sample data, they are marked with italic format.

Table E.1 Sample distribution (speed limit = 30 or 35 mph; median type = undivided)

Access Point Density	Average Annual Daily Traffic																								
	2,000	4,000	6,000	8,000	10,000	12,000	14,000	16,000	18,000	20,000	22,000	24,000	26,000	28,000	30,000	32,000	34,000	36,000	38,000	40,000	42,000	44,000	46,000	48,000	50,000
10	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
70	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
90	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
100	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table E.2 Sample distribution (speed limit = 30 or 35 mph; median type = TWLTL)

Access Point Density	Average Annual Daily Traffic																								
	2,000	4,000	6,000	8,000	10,000	12,000	14,000	16,000	18,000	20,000	22,000	24,000	26,000	28,000	30,000	32,000	34,000	36,000	38,000	40,000	42,000	44,000	46,000	48,000	50,000
10	0	0	0	0	0	0	0	0	1	0	1	2	1	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
40	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
60	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
70	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0	0	0	0	0	0
80	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
90	0	0	0	0	0	0	1	0	0	2	0	1	0	1	0	0	0	1	0	0	0	0	0	0	0
100	0	0	0	0	1	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0

Table E.3 Sample distribution (speed limit = 30 or 35 mph; median type = non-traversable)

Access Point Density	Average Annual Daily Traffic																								
	2,000	4,000	6,000	8,000	10,000	12,000	14,000	16,000	18,000	20,000	22,000	24,000	26,000	28,000	30,000	32,000	34,000	36,000	38,000	40,000	42,000	44,000	46,000	48,000	50,000
10	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
70	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
90	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table E.4 Sample distribution (speed limit = 40 or 45 mph; median type = undivided)

Access Point Density	Average Annual Daily Traffic																								
	2,000	4,000	6,000	8,000	10,000	12,000	14,000	16,000	18,000	20,000	22,000	24,000	26,000	28,000	30,000	32,000	34,000	36,000	38,000	40,000	42,000	44,000	46,000	48,000	50,000
10	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
50	0	0	0	0	1	0	1	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0
60	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
70	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
80	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
90	0	0	0	0	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table E.5 Sample distribution (speed limit = 40 or 45 mph; median type = TWLTL)

Access Point Density	Average Annual Daily Traffic																								
	2,000	4,000	6,000	8,000	10,000	12,000	14,000	16,000	18,000	20,000	22,000	24,000	26,000	28,000	30,000	32,000	34,000	36,000	38,000	40,000	42,000	44,000	46,000	48,000	50,000
10	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	1	0	0	0	1	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
40	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	0	1	1	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
60	0	0	0	0	0	0	0	0	1	1	0	1	0	1	0	0	0	0	1	0	0	0	0	0	0
70	0	0	0	0	1	0	0	0	2	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
80	0	0	0	0	0	1	0	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
90	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0
100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0

Table E.6 Sample distribution (speed limit = 40 or 45 mph; median type = non-traversable)

Access Point Density	Average Annual Daily Traffic																								
	2,000	4,000	6,000	8,000	10,000	12,000	14,000	16,000	18,000	20,000	22,000	24,000	26,000	28,000	30,000	32,000	34,000	36,000	38,000	40,000	42,000	44,000	46,000	48,000	50,000
10	0	0	0	0	0	1	1	0	0	1	1	0	2	1	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	1	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	1	0	0	0	3	0	1	0	0	1	1	0	0	0	0	0	0	0	0
40	0	0	0	0	0	1	1	2	1	0	1	1	0	0	1	0	0	0	0	0	2	0	1	0	0
50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	1	0	0	1	0	0
60	0	0	0	0	0	0	0	0	0	1	0	0	1	0	1	1	1	0	2	0	1	1	0	0	0
70	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	1	0	0	0	0
80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0
90	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	1	0	0	0	0	0	1	0	0	0
100	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table E.7 Sample distribution (speed limit = 50 or 55 mph; median type = undivided)

Access Point Density	Average Annual Daily Traffic																								
	2,000	4,000	6,000	8,000	10,000	12,000	14,000	16,000	18,000	20,000	22,000	24,000	26,000	28,000	30,000	32,000	34,000	36,000	38,000	40,000	42,000	44,000	46,000	48,000	50,000
10	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
60	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
70	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
90	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table E.8 Sample distribution (speed limit = 50 or 55 mph; median type = TWLTL)

Access Point Density	Average Annual Daily Traffic																								
	2,000	4,000	6,000	8,000	10,000	12,000	14,000	16,000	18,000	20,000	22,000	24,000	26,000	28,000	30,000	32,000	34,000	36,000	38,000	40,000	42,000	44,000	46,000	48,000	50,000
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
40	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
60	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
70	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
80	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
90	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table E.9 Sample distribution (speed limit = 50 or 55 mph; median type = non-traversable)

Access Point Density	Average Annual Daily Traffic																								
	2,000	4,000	6,000	8,000	10,000	12,000	14,000	16,000	18,000	20,000	22,000	24,000	26,000	28,000	30,000	32,000	34,000	36,000	38,000	40,000	42,000	44,000	46,000	48,000	50,000
10	0	0	0	0	0	0	0	0	0	0	1	0	0	2	0	2	0	1	1	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	1	0	0	0	0	0
40	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
60	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
70	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
80	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
90	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
100	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

About the Joint Transportation Research Program (JTRP)

On March 11, 1937, the Indiana Legislature passed an act which authorized the Indiana State Highway Commission to cooperate with and assist Purdue University in developing the best methods of improving and maintaining the highways of the state and the respective counties thereof. That collaborative effort was called the Joint Highway Research Project (JHRP). In 1997 the collaborative venture was renamed as the Joint Transportation Research Program (JTRP) to reflect the state and national efforts to integrate the management and operation of various transportation modes.

The first studies of JHRP were concerned with Test Road No. 1—evaluation of the weathering characteristics of stabilized materials. After World War II, the JHRP program grew substantially and was regularly producing technical reports. Over 1,600 technical reports are now available, published as part of the JHRP and subsequently JTRP collaborative venture between Purdue University and what is now the Indiana Department of Transportation.

Free online access to all reports is provided through a unique collaboration between JTRP and Purdue Libraries. These are available at http://docs.lib.purdue.edu/jtrp.

Further information about JTRP and its current research program is available at http://www.purdue.edu/jtrp.

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An open access version of this publication is available online. See the URL in the citation below.

Tarko, A. P., Guo, Q., Narayanan, P. D., Romero, M. A., & Bandaru, V. K. (2025). *A study of suburban arterial safety performance based on median type* (Joint Transportation Research Program Publication No. FHWA/IN/JTRP-2025/07). West Lafayette, IN: Purdue University. https://doi.org/10.5703/1288284317848