<u>GEORGIA DOT RESEARCH PROJECT 23-03</u>

**Final Report**

# DEVELOPING SIGHT DISTANCE GUIDELINES FOR U-TURN MANEUVERS

Georgia Department of Transportation

**Office of Performance-Based Management and Research**

600 West Peachtree Street NW | Atlanta, Ga 30308

**January 2026**

## TECHNICAL REPORT DOCUMENTATION PAGE

| 1. **Report No.** FHWA-GA-26-2303 | 2. **Government Accession No.:** N/A | 3. **Recipient's catalog No.:** N/A |
|---|---|---|
| 4. **Title and Subtitle:** Developing Sight Distance Guidelines For U-Turn Maneuvers | | 5. **Report Date:** January 2026 |
| | | 6. **Performing Organization Code:** N/A |
| 7. **Author(s):** Yichang (James) Tsai (PI), Ph.D., P.E.<br>Atharv Agnihotri (Graduate Research Assistant)<br>Zhijing Huang (Graduate Research Assistant) Scott R O'Brien (Graduate Research Assistant)<br>Venkateshwarlu Balla (Graduate Research Assistant) Zhongyu Yang, Ph.D. | | 8. **Performing Organization Report No.:** 23-03 |
| 9. **Performing Organization Name and Address:** Georgia Institute of Technology<br>790 Atlantic Drive,<br>Atlanta, GA 30332-0355 | | 10. **Work Unit No.:** N/A |
| | | 11. **Contract or Grant No.:** PI# 0019905 |
| 12. **Sponsoring Agency Name and Address:** Georgia Department of Transportation (SPR)<br>Office of Performance-based Management and Research<br>600 West Peachtree St. NW<br>Atlanta, GA 30308 | | 13. **Type of Report and Period Covered:** Final Report (January 2024 – January 2026) |
| | | 14. **Sponsoring Agency Code:** N/A |

**15. Supplementary Notes:**
Conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

**16. Abstract:**
This project, conducted by the Georgia Tech research team in collaboration with the Georgia Department of Transportation (GDOT), aims to develop safe and practical U-turn sight distance (UTSD) guidelines for Reduced Conflict U-turn (RCUT) intersections. The research analyzed video footage from GDOT to quantify U-turn maneuver times under varying median widths and incorporated these observations into sight distance modeling. Results showed that vehicles at wider median noses, where they have storage in the median to position themselves perpendicular to traffic and make a 90 degree turn, completed U-turns in approximately 4.25 seconds; while for narrower median noses, where vehicles can't position themselves perpendicular to traffic and take a 180 degree turn, the u-turning time increased to about 5.8 seconds. These empirical values were integrated with acceleration distance needed to reach 70% of the design speed to derive UTSD using the basic intersection sight distance equation. The resulting UTSD tables provide design guidance across different median widths and design speeds, ensuring adequate time and space for safe U-turn maneuvers. An accompanying Excel tool was also developed to facilitate practical application of the model. Comparisons against models from Florida DOT, Louisiana DOTD (AASHTO case F) and other AASHTO cases demonstrated that the proposed model achieves a balanced level of conservatism and feasibility. Furthermore, crash data analysis from selected RCUT sites confirmed the model's capability to identify locations with insufficient sight distance, supporting its potential to enhance intersection safety and operational performance.

| 17. **Key Words:** AASHTO, Reduced Conflict U-Turn (RCUT), U-Turn Sight Distance, Intersection Design, Median Width, Vehicle Maneuver | | 18. **Distribution Statement:** No Restriction | |
|---|---|---|---|
| 19. **Security Classification (of this report):** Unclassified | 20. **Security Classification (of this page):** Unclassified | 21. **No. of Pages:** 71 | 22. **Price:** Free |

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

GDOT Research Project No. 23-03

Final Report

DEVELOPING SIGHT DISTANCE GUIDELINES FOR U-TURN MANEUVERS

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January 2026

# SI* (MODERN METRIC) CONVERSION FACTORS

## APPROXIMATE CONVERSIONS TO SI UNITS

| Symbol | When You Know | Multiply By | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| in | inches | 25.4 | millimeters | mm |
| ft | feet | 0.305 | meters | m |
| yd | yards | 0.914 | meters | m |
| mi | miles | 1.61 | kilometers | km |
| | | **AREA** | | |
| $in^2$ | square inches | 645.2 | square millimeters | $mm^2$ |
| $ft^2$ | square feet | 0.093 | square meters | $m^2$ |
| $yd^2$ | square yard | 0.836 | square meters | $m^2$ |
| ac | acres | 0.405 | hectares | ha |
| $mi^2$ | square miles | 2.59 | square kilometers | $km^2$ |
| | | **VOLUME** | | |
| fl oz | fluid ounces | 29.57 | milliliters | mL |
| gal | gallons | 3.785 | liters | L |
| $ft^3$ | cubic feet | 0.028 | cubic meters | $m^3$ |
| $yd^3$ | cubic yards | 0.765 | cubic meters | $m^3$ |
| | | NOTE: volumes greater than 1000 L shall be shown in $m^3$ | | |
| | | **MASS** | | |
| oz | ounces | 28.35 | grams | g |
| lb | pounds | 0.454 | kilograms | kg |
| T | short tons (2000 lb) | 0.907 | megagrams (or "metric ton") | Mg (or "t") |
| | | **TEMPERATURE (exact degrees)** | | |
| °F | Fahrenheit | 5 (F-32)/9 or (F-32)/1.8 | Celsius | °C |
| | | **ILLUMINATION** | | |
| fc | foot-candles | 10.76 | lux | lx |
| fl | foot-Lamberts | 3.426 | candela/$m^2$ | cd/$m^2$ |
| | | **FORCE and PRESSURE or STRESS** | | |
| lbf | poundforce | 4.45 | newtons | N |
| lbf/$in^2$ | poundforce per square inch | 6.89 | kilopascals | kPa |

## APPROXIMATE CONVERSIONS FROM SI UNITS

| Symbol | When You Know | Multiply By | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| mm | millimeters | 0.039 | inches | in |
| m | meters | 3.28 | feet | ft |
| m | meters | 1.09 | yards | yd |
| km | kilometers | 0.621 | miles | mi |
| | | **AREA** | | |
| $mm^2$ | square millimeters | 0.0016 | square inches | $in^2$ |
| $m^2$ | square meters | 10.764 | square feet | $ft^2$ |
| $m^2$ | square meters | 1.195 | square yards | $yd^2$ |
| ha | hectares | 2.47 | acres | ac |
| $km^2$ | square kilometers | 0.386 | square miles | $mi^2$ |
| | | **VOLUME** | | |
| mL | milliliters | 0.034 | fluid ounces | fl oz |
| L | liters | 0.264 | gallons | gal |
| $m^3$ | cubic meters | 35.314 | cubic feet | $ft^3$ |
| $m^3$ | cubic meters | 1.307 | cubic yards | $yd^3$ |
| | | **MASS** | | |
| g | grams | 0.035 | ounces | oz |
| kg | kilograms | 2.202 | pounds | lb |
| Mg (or "t") | megagrams (or "metric ton") | 1.103 | short tons (2000 lb) | T |
| | | **TEMPERATURE (exact degrees)** | | |
| °C | Celsius | 1.8C+32 | Fahrenheit | °F |
| | | **ILLUMINATION** | | |
| lx | lux | 0.0929 | foot-candles | fc |
| cd/$m^2$ | candela/$m^2$ | 0.2919 | foot-Lamberts | fl |
| | | **FORCE and PRESSURE or STRESS** | | |
| N | newtons | 0.225 | poundforce | lbf |
| kPa | kilopascals | 0.145 | poundforce per square inch | lbf/$in^2$ |

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

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# LIST OF ABBREVIATIONS

| | |
|---|---|
| AASHTO | American Association of State Highway and Transportation Officials |
| AADT | Annual Average Daily Traffic |
| DOT | Department of Transportation |
| EPDO | Equivalent Property Damage Only |
| FDOT | Florida Department of Transportation |
| FHWA | Federal Highway Administration |
| GDOT | Georgia Department of Transportation |
| ISD | Intersection Sight Distance |
| La DOTD | Louisiana Department of Transportation and Development |
| NCSA | National Center for Statistics and Analysis |
| NHTSA | National Highway Traffic Safety Administration |
| RCUT | Reduced Conflict U-turns |
| SSD | Stopping Sight Distance |
| USDOT | United States Department of Transportation |
| UTSD | U-turn Sight Distance |

# EXECUTIVE SUMMARY

This report presents the findings from a detailed study conducted by the Georgia Tech research team in collaboration with the Georgia Department of Transportation to develop safe and practical U-turn sight distance guidelines for Reduced Conflict U-Turn intersections. The primary objective was to establish design recommendations that enhance U-turn safety based on different vehicle maneuverability and reduce crash risks associated with U-turn movements.

Analysis of near-miss camera video footage from GDOT revealed that the time required for vehicles to complete U-turns varies with median width. The study found that median noses wider than or equal to approximately 14 ft provide sufficient storage for vehicles to reposition perpendicular to traffic and complete a 90-degree turning maneuver. Median noses narrower than 14 ft do not allow this repositioning and instead require drivers to perform a full 180-degree maneuver, which increases the U-turning time. Results indicated that vehicles executing U-turns at wider median nose required an average of 4.25 seconds, whereas vehicles at narrower ones required approximately 5.8 seconds. These times, combined with acceleration distances needed to reach 70% of the design speed (AASHTO, 2018), formed the basis for the U-turn sight distance calculations.

Using the basic intersection sight distance equation(AASHTO, 2018), adjusted for U-turn maneuvering time and acceleration, the team developed U-turn sight distance tables tailored for different median widths and design speeds. These tables provide a comprehensive framework to ensure drivers have adequate space and time to safely complete U-turns without conflicting with oncoming traffic. A spreadsheet tool developed for easy application is also provided as a deliverable. The report also highlights important geometric considerations, such as avoiding negative offsets in turn lane alignment, increasing median opening widths, and incorporating loons to better accommodate trucks and improve overall operational efficiency.

The proposed U-turn sight distance model was compared with existing models from the Florida Departments of Transportation (FDOT) and Louisiana Departments of Transportation and Development (La DOTD), as well as alignment with AASHTO cases. The findings indicate that the model offers a balanced approach with more conservative values than Louisiana's but more realistic and achievable than Florida DOT's model, thus providing practical and safety-conscious design values. Additionally, crash data analysis at select RCUT locations supported the model's effectiveness in identifying areas needing improved sight distances to enhance safety.

# CHAPTER 1. INTRODUCTION

Reduced Conflict U-turns (RCUT) have emerged as a favored traffic management strategy aimed at mitigating the high number of conflict points typically encountered at traditional intersections. This traffic engineering approach minimizes the likelihood of severe collisions while facilitating smoother traffic flow.

Despite their growing popularity, particularly in unsignalized and rural locations, there remains a critical need for well-defined sight distance guidelines tailored specifically for U-turns. The absence of formal AASHTO guidelines (specifically A Policy on Geometric Design of Highways and Streets, commonly known as the Green Book) presents a significant gap in ensuring optimal safety performance at these sites. Insufficient sight distance at these locations may contribute to these crashes (David & Norman, 1975; USDOT). While various states have initiated the development of their own U-turn sight distance criteria, these efforts have yet to converge into a national standard.

Georgia in particular stands to benefit from the establishment of specific unsignalized U-turn sight distance design guidelines. The state has increasingly implemented U-turn into design, such as standard median openings as well as Reduced Conflict U-Turns (RCUTs). A standard RCUT configuration is shown below in **Figure 1**. By creating a standardized framework, the state can ensure that U-turns are implemented consistently and safely across diverse road environments. Such guidelines will not only enhance safety for all road users but also contribute to the overall efficiency and reliability of the state's transportation network.

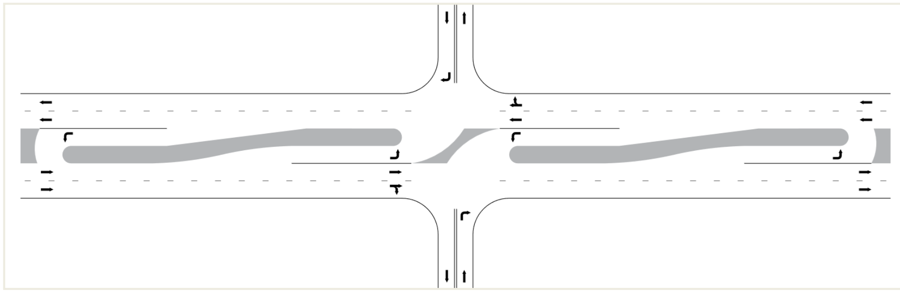


**Figure 1. Graph. FHWA R-CUT Diagram. (FHWA, 2010).**

A structured framework composed of well-reasoned guidelines is required to assist in providing the appropriate details for engineers and planners to make decisions about provisioning an RCUT or unsignalized U-turn design. Therefore, there is an essential need to develop a comprehensive set of sight distance guidelines for the Georgia Department of Transportation (GDOT) to implement to promote and improve roadway safety.

## RESEARCH OBJECTIVES AND TASKS

The objective of this research is to develop a structured set of guidelines and specifications for appropriate sight distances for U-turn maneuvers. To accomplish the goals and the objectives of this research project, the following tasks were performed, sequentially:

1) **Work Task 1:** Conduct a literature review of existing sight distance requirements for U-turn maneuvers.

2) **Work Task 2:** Collect roadway field image data along with GPS data on the selected cases for a sight distance study and perform data analysis.

3) **Work Task 3:** Propose guidelines for sight distance for U-turn movements.

4) **Work Task 4:** Prepare the draft final report by summarizing the research outcomes and completing a final report.

The final deliverable of the research includes U-Turn Sight Distance (UTSD) guideline charts, excel based sight distance calculator tool and recommendations on various U-turn geometric features.

## REPORT ORGANIZATION

This research project report is structured as follows:

- Chapter 1: Introduction - Covers background, research objectives, and tasks.
- Chapter 2: Existing UTSD guidelines - Reviews existing DOT practices and identifies their challenges and shortcomings.
- Chapter 3: Methodology for UTSD guidelines - Presents an enhanced, safer and feasible method developed for recommended UTSD.
- Chapter 4: Data collection and crash analysis - Discusses the means and methods used to collect data and the crash analysis for selected RCUTs using Numetric.
- Chapter 5: Results and Outcomes - Provides descriptive sight distance charts, design recommendations and comparison results.
- Chapter 6: Findings and Recommendations - Summarizes findings and makes future work suggestions.

# CHAPTER 2. EXISTING U-TURN SIGHT DISTANCE GUIDLINES

This chapter introduces sight distance and its importance, reviews the current practices at the national and state levels, and presents the summarized practices and identified gaps.

## UNDERSTANDING SIGHT DISTANCE

Sight distance is a key concept in roadway design and safety, defined as the length of roadway visible to a driver within their line of sight. It's the distance a driver can see ahead along the road, allowing them to detect potential hazards, obstacles, or changes in road conditions. This is especially important in scenarios where drivers need to make decisions in which they may conflict with other vehicles, such as intersections, passing lanes, and median openings. There are three main categories of sight distance values considered in roadway design, as explained below.

Stopping Sight Distance (SSD) is the distance needed for a driver to come to a complete stop after recognizing a hazard on the roadway, such as an obstacle, pedestrian, or another vehicle. It includes the distance traveled during the driver's reaction time (perception-reaction time) and the distance required for the vehicle to decelerate to a stop under prevailing roadway conditions, such as surface friction and grade. Ensuring sufficient stopping sight distance helps prevent rear-end collisions and allows drivers to stop safely in emergency situations (AASHTO, 2018). This is generally provided continuously along all roadways where possible and is the minimum preferred sight distance; the following two types of sight distance add additional time to this minimum to account for specific circumstances.

Intersection Sight Distance (ISD) refers to the distance a driver can see at an intersection before an obstruction blocks their view, focusing on their ability to see crossing roads as well as the road ahead. While stopping sight distance is an acceptable minimum for ISD, larger sight distances are desirable to accommodate certain roadway maneuvers. ISD is calculated from a "decision point" where a vehicle will decide on when to execute its movement. This is generally expressed as a "triangle" of sight beginning at the decision point before the intersection. For departure sight distance which should be provided in each quadrant of each intersection approach controlled by stop or yield signs, the position of the vertex is preferably 14.5 to 18 feet from the edge of the intersecting roadway. However, driver behavior studies indicate that drivers tend to stop 6.5 feet or less from the edge of the intersecting roadway. As such, increasing the vertex position to be closer to 18 feet is preferable (AASHTO, 2018). The preferred sight distance from this triangle is determined based on the expected maneuver and the roadway design speed; relevant maneuvers and their values are discussed later in the report. Having adequate intersection sight distance is crucial for safe maneuvering, as it allows drivers to anticipate potential conflicts and adjust their speed accordingly to safely navigate through the intersection (AASHTO, 2018).

Decision Sight Distance (DSD) is the length of roadway required for a driver to identify an unexpected or challenging information source or condition in a potentially visually cluttered environment. This distance allows the driver to recognize the situation or threat, choose an appropriate speed and path, and execute necessary complex maneuvers. Unlike stopping sight distance, DSD provides drivers with an additional margin for error, enabling them to maneuver their vehicles safely at the same or a reduced speed, rather than merely coming to a stop. This is also recommended to be provisioned as a measure against senior driver-related crashes, providing additional reaction time for these drivers. Consequently, the values for decision sight distance are significantly greater than those for stopping sight distance (AASHTO, 2018).

The Green book required sufficient sight distance at the U-turn crossover both for U-turning drivers and for drivers of other vehicles approaching the crossover, though the details of how this should be determined and calculated are left unclear (AASHTO, 2018). This leaves a variety of questions to be answered, especially considering the unique conditions and movements associated with U-turns - what amount of distance is sufficient? Where should the point of the sight triangle be set? How does the size of the median impact visibility of the opposite lane? How can traffic flow, safety, and driver comfort considerations in visibility be balanced? These questions are explored in the remainder of this report.

## IMPORTANCE OF SIGHT DISTANCE

This section summarizes the most relevant documents reviewed in a literature search. Each provides some amount of context or research findings as they relate to the importance of sight distance and the factors that impact it.

Mitchell (1972) conducted a before-and-after analysis of intersections where various improvements were implemented over a one-year period on each end. The study revealed a 67 percent reduction in crashes (from 39 to 13) after obstructions inhibiting sight distance were removed. This improvement was found to be the most effective among the implemented changes.

Hanna et al. (1976) summarized data collected on comprehensive studies of small city and town intersections. It drew conclusions regarding urban and rural accident patterns and roadway conditions, and how they affect traffic engineering decision-making. The analysis revealed that intersections with poor driver sight distance on one or more traffic approaches tend to have a higher-than-normal accident rate in rural areas.

David and Norman (1975) quantified the relationship between available sight distance and the expected reduction in crashes at intersections. Their study showed that intersections with shorter sight distances generally have higher crash rates. Predicted crash reduction frequencies related to Intersection Sight Distance (ISD) were derived based on their findings.

**Figure 2** that contains Table 13 from David and Norman's study, provides the expected reduction in the number of crashes per intersection per year based on Average Annual Daily Traffic (AADT) and Intersection Sight Distance (ISD). The table shows that as AADT and ISD increase, the expected reduction in crashes also increases, indicating the importance of adequate sight distance in reducing intersection crashes.

**Table 13. Expected Reduction in Number of Crashes per Intersection Per Year (David and Norman, 1979).**

| AADT* (1000s) | Intersection Sight Distance (ft) | | |
|---|---|---|---|
| | 20-49 | 50-99 | > 100 |
| < 5 | 0.18 | 0.20 | 0.30 |
| 5 – 10 | 1.00 | 1.30 | 1.40 |
| 10 – 15 | 0.87 | 2.26 | 3.46 |
| > 15 | 5.25 | 7.41 | 11.26 |

** Annual average daily traffic entering the intersection*

**Figure 2. Screenshot. ISD Values from David and Norman's Study.**

The study conducted by Quan et al. (2022) conducted on a three-mile roadway segment of U.S. 280 in Alabama revealed concerning findings regarding U-turn-related crashes at unsignalized intersections. Analysis of crash data from 2009 to 2014 identified a total of 70 crashes along the selected segment, with a significant portion occurring within a one-mile stretch. Specifically, approximately 30% of the crashes in this segment were U-turn related, resulting in various levels of injuries and property damage. Field observations and measurements indicated a strong correlation between insufficient sight distance (SD) for U-turns and terrain characteristics such as elevation, grade change, and curvature.

The research team's review highlighted the critical role of adequate sight distance in mitigating U-turn-related crashes at median openings on high-speed multilane highways. Limited sight distance was identified as a potential contributing factor to the elevated crash rates observed in the study area. This underscores the importance of ensuring sufficient sight distance for U-turn movements, particularly at unsignalized intersections where median openings are common. The study aimed to develop a cost-efficient and safe method to estimate sight distance for U-turns, providing engineers with valuable tools to identify and address potential safety concerns on roadway segments prone to U-turn-related crashes.

Strate's analysis in Federal Highway Administration examined 34 types of improvements made in Federal Highway Safety Program projects (Strate, 2024). The results indicated that sight distance improvements were the most cost-effective, with a benefit-cost ratio of 5.33:1. This indicates a substantial return on investment in improving sight distance at intersections, emphasizing the significant impact such enhancements can have on enhancing roadway safety. By ensuring adequate sight distance, transportation agencies can effectively reduce the occurrence of severe crashes, thereby save lives and minimize injuries on roadways.

## REVIEW OF CURRENT PRACTICES

This section covers the elements of nation and state level guidance on U-turn sight distance requirements in order to provide a basis of work on which to develop standards for Georgia. Nationwide practices provide an adaptable formula for calculation and key sight distance considerations at all intersections; state practices tend to expand this formula U-turn specific, with additional details such as roadway geometry and design vehicles.

### Nationwide Practices

The Green Book highlighted Perception-Reaction Time (PRT) as a critical factor in Intersection Sight Distance (ISD) determination, with variations in PRT assumptions across different scenarios, typically ranging from 2.0 to 2.5 seconds. The Gap Acceptance model proposes a critical gap approach for ISD calculation, potentially offering a better fit for aging drivers by considering their gap acceptance behavior (AASHTO, 2018).

Research by Yan et al. (2007) suggests that older drivers tend to accept larger gaps than younger drivers, particularly at lower speeds, and rely more on perceived sight distance at higher speeds. This indicates a potential need for adjustments in ISD requirements based on driver age and prevailing traffic conditions. Existing AASHTO guidelines recommend calculating ISD using the following formula (AASHTO, 2018):

$$ISD = 1.47 \times V \times t_g$$

**Figure 3. Equation. ISD.**

Where $V$ represents the design speed of the major road and $t_g$ denotes the time gap for a minor road vehicle to enter a major road. Notably, the time gap value varies for different vehicle types, including passenger vehicles, single-unit trucks, and combination trucks, with larger vehicles having a larger time gap. Time gaps for varying situations have been developed by AASHTO-supported studies based on a combination of research of driver behavior and applied physics, using expected acceleration and deceleration values to determine safe times to complete a movement. Driver behavior values generally utilize the 95th percentile of observed driver behavior, multiplied by a safety factor of 50%, applied to the worst expected roadway conditions (i.e. worn tires on a wet roadway) to determine safe values.

Example values for these time gaps, as well as a summary of calculations for various design speeds, are listed in **Figure 4** below. "Case B1" refers to the sight distance vehicles required for making a left turn from the minor roads (stop controlled). Notably, case B1 is for turns onto a 2-lane highway with no median, indicating that a time gap for a U-turn on a wider, divided road may need to be longer.

Table 9-6. Time Gap for Case B1, Left Turn from Stop

| Design Vehicle | Time Gap ($t_g$)(s) at Design Speed of Major Road |
|---|---|
| Passenger car | 7.5 |
| Single-unit truck | 9.5 |
| Combination truck | 11.5 |

**U.S. Customary**

$$ISD = 1.47\, V_{major}\, t_g$$

where:

$ISD$ = intersection sight distance (length of the leg of sight triangle along the major road) (ft)

$V_{major}$ = design speed of major road (mph)

$t_g$ = time gap for minor road vehicle to enter the major road (s)

| U.S. Customary | | | |
|---|---|---|---|
| Design Speed (mph) | Stopping Sight Distance (ft) | Intersection Sight Distance for Passenger Cars | |
| | | Calculated (ft) | Design (ft) |
| 15 | 80 | 165.4 | 170 |
| 20 | 115 | 220.5 | 225 |
| 25 | 155 | 275.6 | 280 |
| 30 | 200 | 330.8 | 335 |
| 35 | 250 | 385.9 | 390 |
| 40 | 305 | 441.0 | 445 |
| 45 | 360 | 496.1 | 500 |
| 50 | 425 | 551.3 | 555 |
| 55 | 495 | 606.4 | 610 |
| 60 | 570 | 661.5 | 665 |
| 65 | 645 | 716.6 | 720 |
| 70 | 730 | 771.8 | 775 |
| 75 | 820 | 826.9 | 830 |
| 80 | 910 | 882.0 | 885 |

**Figure 4. Screenshot. Intersection Sight Distance (ISD) Calculation Tables (AASHTO, 2018)**

Another case applicable to unsignalized median openings, Case F, refers to the time required to make left turns from the major road at the median opening or the intersection. The suggested time gap is 2 seconds shorter for a passenger car than suggested in case B, a gap of 5.5 seconds. However, Case F also includes adjustments for number of lanes and the width of the median, in a simplified form; AASHTO suggests adding 0.5 seconds for every lane crossed past the first and to roughly convert the width of the median into an equivalent number of lanes; for example, an 18 foot wide median would convert to about one and a half lanes, adding 0.75 seconds. Case F is described in **Figure 5,** shown below.

Table 9-16—Time Gap for Case F, Left Turns from the Major Road

| Design Vehicle | Time Gap ($t_g$)(s) at Design Speed of Major Road |
|---|---|
| Passenger car | 5.5 |
| Single-unit truck | 6.5 |
| Combination truck | 7.5 |

Note: Time gaps are for a stopped vehicle turning left from a two-lane highway with no median

*For multilane and/or divided roadways*—For left turns on two-way roadways across more than one opposing lane, including turn lanes, add 0.5 s for passenger cars or 0.7 s for trucks for each additional lane to be crossed in the left-turn maneuver in excess of one lane. Where the left-turning vehicle must pass through a median, the median width should be converted to an equivalent number of lanes; for example, an 18-ft [5.5-m] median would be equivalent to one and a half lanes and crossing through the median would require an additional 0.75 s for a passenger car and 1.05 s for a truck. The table also contains appropriate adjustment factors for the number of major-road lanes to be crossed by the turning vehicle. The unadjusted time gap in Table 9-16 for passenger cars was used to develop the sight distances in Table 9-17.

**Figure 5. Screenshot. Timing and Adjustments for Case F. (AASHTO, 2018)**

While these cases are well-documented and supported by research, they are not directly comparable to U-turn movements, and as such may not be an ideal basis for guideline development. However, the principles of their design and resulting sight distance values are a valuable reference point for the development of more applicable guidelines. Basing SD guidelines on a combination of driver behavior, applied physics, and relevant roadway geometry factors is an acceptable baseline for the guidelines.

AASHTO also emphasized the importance of median width in U-turn design and safe driver behavior. Undesirable driving behaviors, such as side-by-side queuing, angle stopping, and encroachment into through lanes, are commonly observed when vehicles compete for limited space within narrow medians.

The frequency of these undesirable behaviors and associated crashes has been shown to decrease as median width increases, indicating that wider medians are generally safer. Medians that are too narrow, particularly those between 4 to 8 feet, are insufficient for accommodating left-turning vehicles and often lead to encroachment into adjacent lanes by other motorists trying to avoid partially stopped vehicles. Therefore, median widths of 12 to 30 feet are recommended as they provide adequate protected storage space for left- and U-turning vehicles at intersections (AASHTO, 2018). The median width and the number of opposing lanes influence the distance traveled in the execution of a U-turn maneuver, making these design considerations highly relevant for this report.

**State Practices**

Specific guidelines for U-turn sight distance requirements are rare at the state level. A review of publicly available guidelines revealed only two states with such guidelines, Florida and Louisiana. The lack of clear, widely applicable guidelines at both the state and federal levels highlight the need for additional research in this area.

The guidelines developed by the Florida DOT model the acceleration time of the design vehicle to come to the design speed of the roadway, accounting for the length of the U-turn, standard perception-reaction time, dimensions of the design vehicle and potential opposing vehicles, acceleration of the U-turning car, and the distance that would be traveled by the traversing vehicle and opposing vehicles during the maneuver and acceleration. The method is conservative in its assumptions on acceleration, using a speed of 0 mph from the point after a vehicle completes its turning portion of the maneuver. The calculated sight distance is also reduced by the distance traveled by the turning vehicle as it comes to speed, a large and significant reduction that may not be perfectly applicable.

Calculations are shown below, alongside the AASHTO-produced figures they reference for acceleration (FDOT, 2019).

**Example**

Design Speed (V) = 45 mph

Perception-Reaction Time (PRT) = 2.5 seconds

Distance to accelerate from 0 to 45 mph = 580 ft (refer to the distance-acceleration relationships shown in AASHTO Green Book)

Design vehicle length = 19 ft, a passenger vehicle

Turn radius = 15 ft

Clearance = 50 ft

We assume that the vehicle accelerates from 0 mph after completing turning portion of movement.

Calculation of total travel time and corresponding sight distance:

Distance traveled along circular part of U-turn = pi * turn radius = 47.1 ft

Total distance traveled = 47.1 + 580 + 19 = 646.1 ft (including passenger vehicle tailing length)

Time to travel ~645 ft at an acceleration rate of 3.77 ft/sec$^2$ = (645*2/3.77) = 18.5 seconds.

Total time = PRT + travel time = 2.5 + 18.5 = 21 seconds.

Intersection Sight Distance = 1.47 * V * Total time = 1.47*45*21 = 1,390 ft

Adding clearance distance = 1,390 + 50 = 1440 ft

Sight distance = total distance – distance traveled while accelerating = 1440 – 580 = 860 ft

The Louisiana Department of Transportation and Development (La DOTD) utilizes a similar, simplified method for U-turn sight distance determination, based on AASHTO left-turn sight distance guidelines (LaDOTD, 2020). The required sight distance is based on a combination of the design vehicle, number of lanes the maneuver is expected to involve crossing, and the design speed of the roadway. Their exact equation is not stated but can be assumed to be based on speed of travel of opposing traffic and acceleration speed of the design vehicle. If sight distance is measured to be less than the design value suggested in the table below, a signal is required for protected U-turn and left-turn movements. Notably, these guidelines are listed in their Traffic Signal Manual, implying they may not be acceptable in unsignalized applications (LaDOTD, 2020). One unsignalized U-turn design document used in Louisiana referenced the table developed by the Florida DOT as described above (LaDOTD, 2013). The values used by La DOTD in this sight distance methodology are shown in **Figure 6.**

| DESIGN SPEED (MPH) | LEFT TURN SIGHT DISTANCE (FT) FOR PASSENGER CARS BASED ON NUMBER OF OPPOSING LANES | | |
|---|---|---|---|
| | 1 - LANE | 2 - LANE | 3 - LANE |
| 15 | 125 | 135 | 145 |
| 20 | 165 | 180 | 195 |
| 25 | 205 | 225 | 240 |
| 30 | 245 | 265 | 290 |
| 35 | 285 | 310 | 335 |
| 40 | 325 | 355 | 385 |
| 45 | 365 | 400 | 430 |
| 50 | 405 | 445 | 480 |
| 55 | 445 | 490 | 530 |
| 60 | 490 | 530 | 575 |

This information is for Center Left Turn Lanes with no median.
The above figure should be adjusted for wide medians or offset turn lanes.
(See AASHTO Green Book - Case F - p.9-56)

| Design vehicle | Time gap (tg) (seconds) at speed of major road |
|---|---|
| Passenger car | 5.5 |
| Single-unit truck | 6.5 |
| Combination truck | 7.5 |

**Figure 6. Screenshot. Louisiana's U-Turn Sight Distance Tables.**

Although La DOTD provides similar design vehicle categories of time gaps, their time gaps in La DOTD are different from the ones in Florida. There is no detailed description of the factors impacting these time gaps, though they appear to be using the less conservative AASHTO-defined ISD Case F, “Left Turns from the Major Road”, as opposed to Case B1, “Left Turn from Stop”. The differences in these values range from 2 seconds of time gap (more than 25% difference) at the passenger car level to 4 at the combination truck level. Neither state clearly justifies this choice, despite its potential implications on safety. Further work is needed to determine the appropriate time gap for Georgia. The Florida Department of Transportation (FDOT) has developed detailed calculations for U-turn sight distances. However, these calculations are based on assumptions and parameters that may not be applicable to other states, such as Georgia, due to differences in driving behaviors, road geometries, and traffic patterns. La DOTD has a similar set of guidelines but has based them on a less conservative set of initial parameters, again leaving Georgia with a wide range of potential values to use in their own guidelines.

Georgia’s GDOT Design Policy Manual adopts the AASHTO Green Book criteria as the standard for Intersection Sight Distance. Variations from minimum sight distance requirements set by AASHTO for ISD or any other type of sight distance requires a comprehensive study and “Design Variance” to be approved by the Chief Engineer. Because of this adherence to AASHTO’s sight distance methodologies, there are no specific provisions for sight distance as it relates to U-turn design. However, the manual does outline several related design considerations. For example, it allows the spacing between the minimum median opening can be closer than 1000 ft in urban areas and 1320 ft in rural areas. It also advises median openings on six-lane roadways needs specifically to be studied to assign a proper control mechanism, such as an RCUT, two-way stop, or signal control (GDOT, 2024). The manual also points to an NCHRP report on U-turn safety as a reference for design. This report points to opposing turn lane obstructions as a potential safety concern, suggests that ISD may be affected by the grade of the area and the geometry of the median opening, and references the final sight distance values calculated for U-turns by FDOT (Potts, 2004).

In conclusion, the review of current practices highlights the absence of specific specifications for U-turn sight distances from FHWA, indicating a need for further guidance in this area. While AASHTO provides general specifications for ISD, they do not specifically address U-turns. Although the Gap Acceptance model proposed by AASHTO offers a potential solution by considering driver behavior, it still lacks specific guidelines for U-turn sight distance determination. State level guidelines have increased specificity, but do not appear to consider the range of variables and contextual factors that may be necessary to ensure safety. There are no detailed descriptions of the factors used in deciding these time gaps, which may include factors such as U-turn geometry, intersection configurations, and driver behavior.

## SUMMARY

### Overall Findings

Sight distance stands as a critical determinant of safety and comfort, particularly in turning maneuvers along roadways. The ability of drivers to accurately perceive potential hazards and react in a timely manner significantly hinges on their line of sight.

Inadequate sight distance not only jeopardizes the safety of drivers but also compromises the overall comfort and ease of navigating through intersections, especially during turns where visibility is crucial for assessing oncoming traffic and making informed decisions. Improvements to sight distance tend to be cost effective measures for enhancing safety. Ensuring sufficient sight distance is, therefore, a key factor in mitigating the risk of collisions and enhancing the overall driving experience.

At the state level, standardized guidelines regarding sight-distance requirements are not available or not developed in most states. Using Florida and Louisiana's implemented and tested standards as a reference point, transportation authorities and engineers can establish their own sight distance criteria that align with the unique characteristics and needs of their respective regions, thereby promoting consistency and safety in roadway design and management.

Existing sight distance standards typically consider a limited number of factors that are deemed essential for ensuring safe turning maneuvers and overall roadway safety. Among these factors, design vehicle factors, roadway design speed, and expected route of traversal (such as number of lanes to be crossed in maneuver) are deemed most important.

**Gaps in Existing Research**

The research landscape concerning U-turn sight distances reveals several notable gaps and limitations:

1) Absence of Specific Guidelines: Existing literature and guidelines lack specificity when determining sight distances tailored for U-turn maneuvers. Most guidelines primarily focus on conventional U-turn designs, overlooking the unique requirements of alternative designs.

2) Neglect of Alternative Designs: The predominant attention given to conventional U-turn designs sidelines alternative configurations, such as Reduced Conflict Intersection Crossing U-turns (RCUTs) or directional U-turns. Consequently, there's a dearth of guidance on sight distances tailored to these alternative designs.

3) Ignorance of Vehicle-Specific Turning Radii: The failure to consider the diverse turning radii of different vehicle types during sight distance calculations poses a safety risk. This oversight disregards the varying maneuvering capabilities of vehicles and may compromise safety at U-turn locations.

4) Limited Exploration of Driver Behavior Impact: The influence of U-turn sight distances on driver behavior and comfort, particularly regarding gap acceptance and maneuvering decisions, remains inadequately explored. Understanding these behavioral dynamics is crucial for devising effective safety measures. This also includes the impact of drivers' age and their physical ability in turn maneuver.

5) Assumptions of Standard Maneuvers: Many studies assume a standard 180-degree turn and constant acceleration throughout the U-turn maneuver. However, real-world scenarios often involve variations in turning radii and

acceleration rates among different vehicle types, necessitating a more nuanced approach.

6) Consideration of Different Viewing Angles: The angle and position of a vehicle relative to traffic greatly influences its effective sight distance. For example, a vehicle parallel to traffic will have different visibility compared to a vehicle that has pulled forward and is now nearly perpendicular to traffic. As suggested, a graphic will be added here to show this. We will likely have to make it ourselves, as I could not find a suitable existing graphic to demonstrate this concept.

7) Consideration of Offset Distances: The visibility of oncoming traffic during U-turn maneuvers through median openings is significantly influenced by median offset distances, as shown in **Figure 7** below. In this case, offset distances refer to the lateral distance median turn lanes are offset from the center. In the case of negative offsets, there is additional space placed between the turn lane and the opposing direction of traffic, causing vehicles in the opposing median turn lane to block views of oncoming traffic; positive offsets place the turn lane past opposing turn lanes, providing less obstructed views. Despite the impact this can have on sight distance, existing guidelines and research efforts often inadequately consider these factors, compromising the accuracy of visibility assessments.

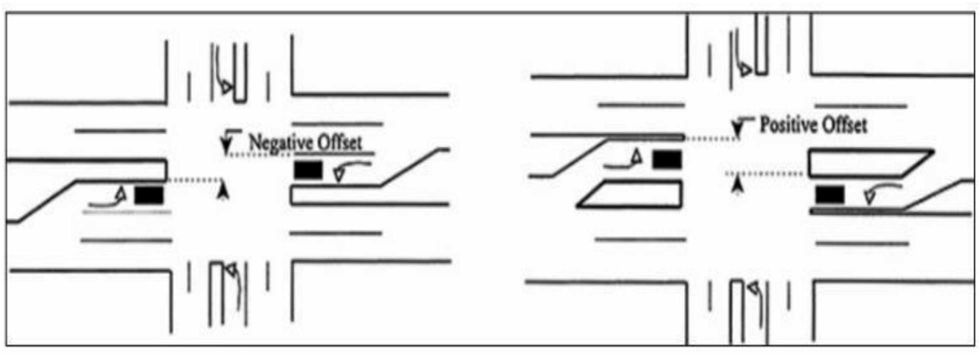



**Figure 7. Graph. Offset Distances. (AASHTO, 2018)**

Addressing these gaps in the research is essential for developing comprehensive and effective guidelines for U-turn sight distances, thereby enhancing roadway safety and operational efficiency.

# CHAPTER 3. METHODOLOGY FOR DEVELOPING, VALIDATING AND REFINING U-TURN SIGHT DISTANCE MODEL

The U-Turn Sight Distance (UTSD) model is developed based on a detailed study of RCUTs in Georgia, based on the following rationales:

## BASE RATIONALE

The UTSD model is designed to determine the minimum distance a driver must observe oncoming traffic to safely execute a U-turn maneuver without conflict. This model is grounded in the following key considerations:

- Total U-turn Maneuver time ($t_{ut}$): The duration from the moment a vehicle initiates a U-turn from a complete stop to the point at which it aligns parallel with the major roadway lane and accelerates to match the roadway speed.
- Major Road Speed ($V_d$): The velocity of the oncoming vehicle on the major road, which influences the required stopping sight distance (SSD) to prevent potential collisions. This speed may be based on the design speed, posted speed limit, or any other appropriate speed metric as per state practices for the major road where the U-turn occurs.

### Developing the base

A U-turn maneuver involves the interaction of two vehicles: one executing a U-turn and another traveling on the major road. The maneuver typically entails a 90-degree like left turns or 180-degree U-turns from the right lane into the left lane of the same roadway, depending on the vehicle's position at the decision point and the median width of the U-turn. To model this scenario accurately, the following guidelines and parameters are utilized:

1) Left-Turn at an Intersection: The U-turn is modelled similarly to a left-turn maneuver at an intersection, as described in Cases B1 and F of the AASHTO Green Book. These cases provide insight into the geometric and operational characteristics of left-turn movements, which are analogous to U-turns in terms of maneuver complexity and required sight distance.

2) Stopping Sight Distance: The SSD for the major-road vehicle is determined following AASHTO guidelines. SSD represents the minimum distance needed for a vehicle to stop after perceiving an obstacle, accounting for perception-reaction time and braking distance.

3) Driver Behaviour Parameters: AASHTO parameter tables for acceleration, deceleration, perception-reaction time (PRT), and maneuver times are adapted to account for the specific dynamics of U-turns. These adjustments ensure that the model reflects the unique characteristics of U-turn maneuvers.

4) Median and Median Nose: A median is the area between opposing travel lane edges. A median nose refers to the pointed or rounded end of a raised median. The width of the median nose is defined as the distance between the inside edge of the turning lane and opposing travel way, including the inside shoulders as shown in **Figure 8**. The median end shape can directly alter the effective turning path the design vehicle can make. The shape of a median nose should be designed to accommodate the turning path of the design vehicle (TxDOT).

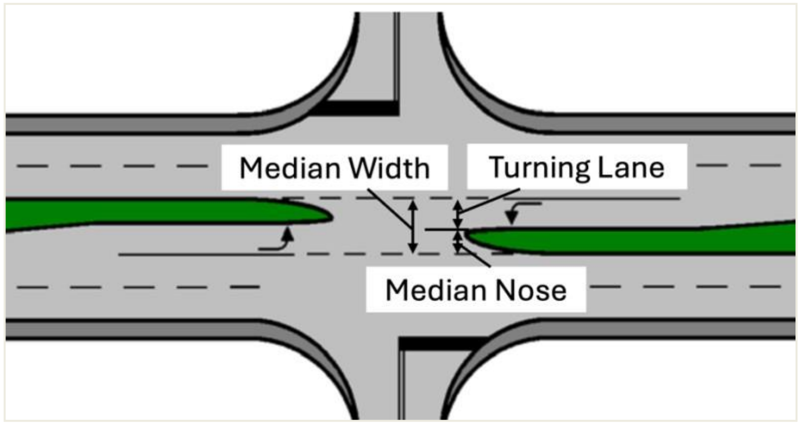



**Figure 8. Graph. Sample Illustration of Median Nose.**

5) Near-Miss Considerations: The model incorporates near-miss scenarios, as per Georgia Department of Transportation (GDOT) request, to account for situations where conflicts nearly occur without actual collisions.

Building upon these considerations, the UTSD is calculated using the following formula:

$$USTD = 1.47 \times V_d \times t_{ut}$$

**Figure 9. Equation. UTSD.**

where:

$V_d$ = the speed of the oncoming vehicles in miles per hour (mph),

$t_{ut}$ = the Total U-turn maneuver time in seconds.

The values for the design speed ($V_d$) of the major road and the Total U-turn maneuver time ($t_{ut}$) were directly measured at U-turn locations, providing empirical data that serves as the ground truth for these parameters. This approach enhances the reliability and redundancy of the model. Subsequently, UTSD is calculated using the selected formula.

**Measuring total U-turn maneuver $t_{ut}$**

The development of the U-Turn Sight Distance model is grounded in established guidelines and empirical research to ensure that drivers can execute U-turn maneuvers safely and efficiently. To derive $t_{ut}$ from the collected U-turning vehicle data, the GT team has developed a comprehensive methodology comprising two integral components based on the two stages of U-turning process: U-turning time which can be directly extracted from the near-miss camera footage and accelerating distance (or time) (AASHTO, 2018), as shown in **Figure 10**.

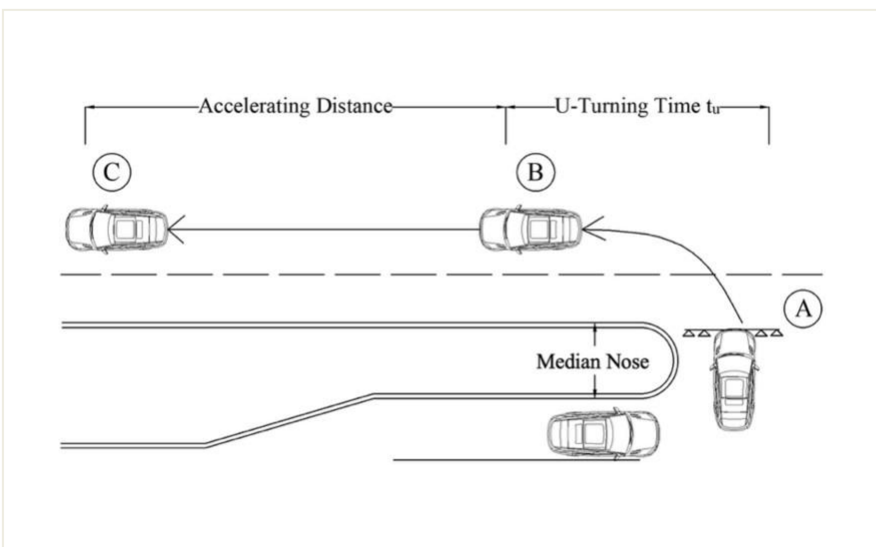



**Figure 10. Graph. Two Components of Total U-turn Maneuver Time.**

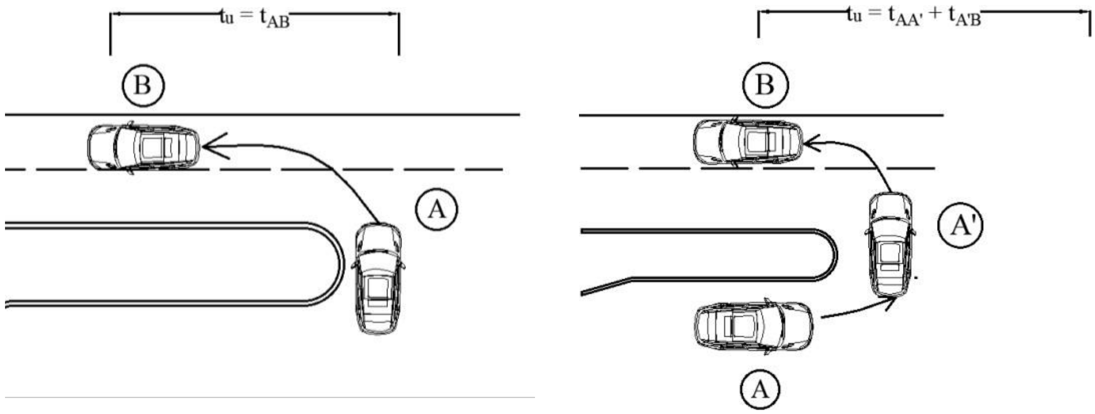
1) **U-Turning Time ($t_u$):** A pivotal component of this model is the determination of U-turning time, denoted as $t_u$, which represents the time interval required for

a vehicle to complete a U-turn, starting from a complete stop until it becomes parallel with the major road lane. When the median provides sufficient width to shield a stopped vehicle within the opening, drivers can reposition the vehicle prior to initiating the maneuver, resulting in a shorter U-turning time on the opposing roadway.

Median nose width plays a critical role in determining how vehicles execute U-turns. Based on different median nose's width, we defined two types of U-turning time (90-degree turn and 180-degree turn), as shown in **Figure 11 (a)** and **(b)**.

Although no formal design guidance specifies a required median nose width for U-turn operations, a width of approximately 14 ft was observed to represent a practical minimum for allowing most passenger cars to reposition within the median opening under common practice. Accordingly, the study adopted 14 ft as the threshold for distinguishing between 90-degree and 180-degree U-turn scenarios. This threshold applies to passenger cars only and should be interpreted as a minimum suggested value; vehicles may partially occupy the adjacent turning lane to stop and complete a two-stage U-turn maneuver.

This approach provides a clear and methodical way to calculate gap time with minimal room for error. It is particularly effective when utilizing available camera footage, as it aligns with the field of vision and ensures consistency in measurements.




(a) 90-degree U-turn (b) 180-degree U-turn

**Figure 11. Graph. Depiction of a Car Performing a U-Turn Maneuver from Point A to Point B.**

2) **Accelerating Distance:** This factor incorporates the distance over which the U-turning vehicle accelerates, ensuring compatibility with the Green Book. According to the Green Book Chapter 9, page 9-43, Section 9.5.3.2.1, AASHTO recommends that most vehicles on the major road should not reduce their speed to less than 70% of their initial speed (AASHTO, 2018). This stipulation serves as a supplementary factor to the U-turn maneuver time. Specifically, 70% of the major road vehicle's speed is utilized to determine the corresponding value from **Figure** 12**.**

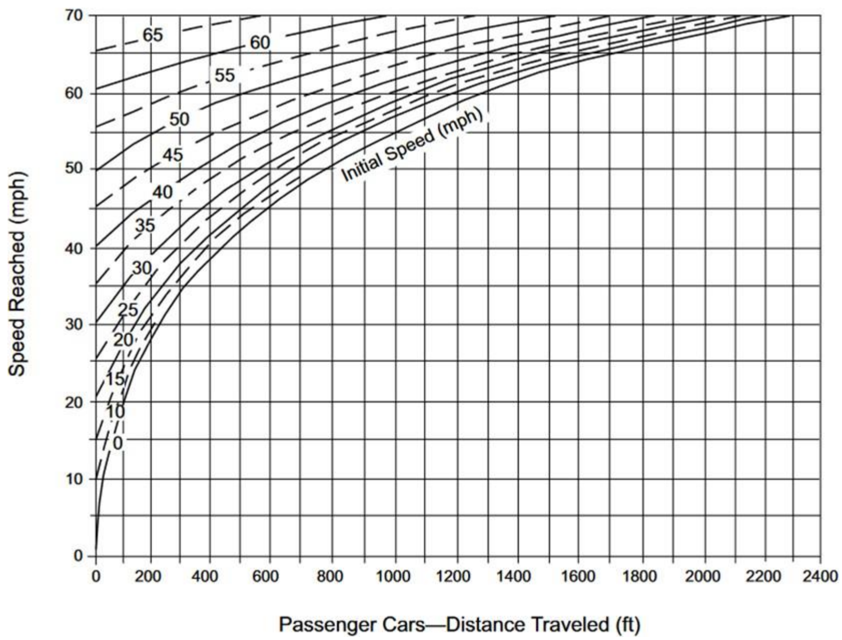



**Figure 12. Chart. Reference Table for Standard Accelerations Over Varying Distances and Starting Speeds of Passenger Cars. (AASHTO, 2011)**

*Note*: *The distance derived from the AASHTO acceleration chart, as illustrated in Figure 10, is added to the UTSD calculated using the U-turn maneuver time, rather than the time required for acceleration. This approach simplifies calculations, as the AASHTO charts directly provide the distance, which would be computed regardless. The cumulative gap time and accelerating time can subsequently be back calculated from the UTSD and vehicle speed, as detailed in Appendix B of thereport*.

Thus, the calculation equation for the UTSD should be:

$$USTD = 1.47 \times V_d \times t_u + D_{acceleration} = 1.47 \times V_d \times t_{ut}$$

**Figure 13. Equation. UTSD Calculation.**

Then we can come back to calculate the total U-turn maneuver time $t_{ut}$ after determining the two components of UTSD. This methodology offers advantages such as streamlined calculation process, minimized potential measurement errors, aligned with the field of vision when using camera footage provided by GDOT, and adherence to the established AASHTO standards. Furthermore, the approach facilitates the establishment of clear boundary conditions, thereby enabling the potential automation of the gap time extraction process through artificial intelligence technologies.

**Correction factor for trucks**

To simplify the presentation of sight distance requirements for trucks, this study proposes the use of a correction factor rather than developing a separate sight distance chart. This approach is intended to streamline the design process while still accounting for the operational differences between trucks and passenger cars. From the available video footage, only one RCUT location was identified where trucks regularly performed U-turns. This limited data availability significantly restricts the generalizability and statistical robustness of the analysis. Moreover, no dedicated acceleration charts currently exist for trucks, further complicating the direct computation of sight distance based on vehicle dynamics.

To address this limitation, the gap times table provided in the Green Book for comparable maneuvers was adopted as reference(AASHTO, 2018). Specifically, Case B1 - Left Turn from a Stop was used as a reference scenario, as it closely resembles the maneuver performed during a U-turn at an RCUT. By comparing the gap time values for trucks and passenger cars under this case, we derived a consistent correction factor based on the ratio of their respective values. This correction factor can be applied to the standard U-turnsight distance calculations for passenger vehicles to estimate the corresponding values for trucks. **Table 1** presents the derived correction factors, which are recommended for use in RCUT designs that accommodate commercial vehicle movements.

**Table 1. Common Ratio Derived from AASHTO Case-B1 for Different Vehicle Types.**

| S.no | Vehicle Type | Gap times for AASHTO Case - B1 | Common Ratio (Correction Factor) |
|---|---|---|---|
| 1 | Passenger Car | 7.5 | 1 |
| 2 | Single-Unit Truck | 9.5 | 1.27 |
| 3 | Combination Truck | 11.5 | 1.53 |

## MODEL COMPARISON

This section outlines the methodology employed to validate and enhance the accuracy of the UTSD model. The process involved a comprehensive comparison of measured gap times, alignment with established AASHTO guidelines, and analysis of real-world crash data, thereby ensuring the model's reliability and applicability in practical scenarios.

### Comparison of the UTSD model with State DOT Models.

The initial step entailed a comparative analysis of sight distances derived from the model against those adopted by other state DOTs. This comparative study aimed to evaluate the consistency and alignment of the model's sight distances with those established by other state DOTs, assess whether the model provides adequate safety margins by analyzing near-miss scenarios captured on camera, and refine model parameters by identifying discrepancies between the model and observed data to enhance predictive accuracy. This comparative approach facilitated the identification of areas for improvement, leading to a more robust and reliable UTSD model. Ideally, the proposed UTSD model will provide an appropriate sight distance, with the La DOTD and FDOT methodologies serving as benchmarks to help contextualize the model's outputs.

**Alignment with AASHTO Gap Time Guidelines for Intersections.**

The second comparison component involved comparing the model's gap times with the time gap guidelines provided by the American Association of State Highway and Transportation Officials (AASHTO) and the Manual on Uniform Traffic Control Devices (MUTCD). Specifically, we referenced:

- AASHTO Intersection Case B1: Left turn from the minor road at stop-controlled intersections, which recommends a time gap of 7.5 seconds for passenger cars, 9.5 seconds for single-unit trucks, and 11.5 seconds for combination trucks.
- AASHTO Intersection Case C2: Left or Right turn from the minor road at yield-controlled intersections, which recommends a time gap of 8 seconds for passenger cars, 10 seconds for single-unit trucks, and 12 seconds for combination trucks.

By aligning the model's gap times with these established guidelines, we ensured that the UTSD model adheres to recognized safety standards, thereby enhancing its credibility and applicability. Ideally, the model should have greater sight distance values as U-turn maneuvers require longer gap times.

**Analysis of Crashes at U-Turn Locations**

The final comparison step involved analysing U-turn sites with recorded crashes and near misses to assess the effectiveness of the model in real-world conditions. Utilizing historical crash data and analytical tools, we:

1) Identify Problematic Sites: Pinpointed U-turn sites with a history of crashes potentially related to sight distances.

2) Compare Model Predictions: Compared the sight distances predicted by the model with those observed at these problematic sites.

3) Investigate Contributing Factors: Examined site characteristics, including road geometry and traffic conditions, to identify factors contributing to crashes.

This analysis provided valuable insights into the practical performance of the model, highlighting areas for further refinement and ensuring its relevance in preventing real-world traffic incidents. Ideally, the model should suggest a value greater than the sight distance identified at the problematic intersection.

# CHAPTER 4. DATA COLLECTION AND CRASH ANALYSIS

This section outlines the data acquisition strategy and its critical role in understanding the operational and safety dynamics of RCUT intersections. Gathering reliable data was essential for assessing traffic behavior, flow efficiency, and potential safety concerns at these locations. For newly implemented RCUT intersections, a structured, multi-step approach was followed to collect and prepare the data:

**Step 1: Coordination with DOT Officials.**

The process was initiated by engaging with officials from the GDOT to align the project goals with their expectations. This collaboration helped refine the data acquisition strategy. During the meeting, GDOT shared data from eight RCUT sites, listed in **Table 2**, which was used for a detailed crash record analysis.

**Step 2: Crash Data Analysis Using Numetric.**

Numetric, a data visualization platform partnered with AASHTOware, was utilized to examine historical crash data for the selected intersections. Key metrics such as Equivalent Property Damage Only (EPDO) scores, crash frequency, rates, contributing factors, and locations were analysed. This preliminary analysis helped identify crash-prone RCUT locations and explore potential causes.

**Step 3: Video-Based Observation at U-Turns.**

Near-miss camera videos have been collected by GDOT at these RCUT intersections to record vehicle movements, focusing particularly on U-turn sections The footage offered valuable insights into driver behaviour and vehicle gap acceptance, which are crucial for identifying near-miss situations. Although no collisions were directly observed, the videos revealed conditions that may contribute to future accidents.

**Table 2. Eight RCUT Locations and Their Respective Co-ordinates, AADT and Posted Speed.**

| Site | RCUT location | Installation date | Latitude and Longitude | AADT | Posted Speed |
|---|---|---|---|---|---|
| **1** | Jimmy Campbell Pkway (US-278) @ S Main St/West Ave in Dallas, Georgia (GDOT District 6) | Not provided | 33°54'54.1"N 84°50'43.6"W | 12900 | 55 |
| **2** | US301 & Singleton Ave/ Buttermilk Rd in Sylvania, GA 30467 (GDOT District 5) | Not provided | 32°45'44.5"N 81°38'50.3"W | 2030 | 55 |
| **3** | US 129/SR 11 @ Old Swimming Pool Rd in Jackson (city of Jefferson) County, GA 30549 (GDOT District 1) | 12/01/2021 | 34°06'45.8"N 83°35'54.6"W | 12250 | 45 |
| **4** | SR 365 & Mud Creek Rd in Hall County, GA 30510 (GDOT District 1) | 06/10/2024 | 34°26'09.7"N 83°37'54.7"W | 12650 | 45 |
| **5** | SR 296 & Fenns Bridge Rd (SR 540) in Jefferson County, GA 30832 (GDOT District 2) | Not provided | 33°09'26.8"N 82°27'22.6"W | 2425 | 55 |
| **6** | SR 125 & Huntley Dr in Valdosta, GA, 31605 (GDOT District 4) | Not provided | 30°54'26.4"N 83°15'51.2"W | 14700 | 45 |
| **7** | SR 365 & Yonah Post Rd in Alto, GA, 30510 (GDOT District 1) | 8/31/2024 | 34°26'46.8"N 83°37'22.0"W | 12200 | 45 |
| **8** | Hwy 411 & Macedonia Rd in Bartow County, GA, 30145 (GDOT District 6) | Not provided | 34°12'29.9"N 84°58'51.3"W | 8700 | 65 |

## COMPREHENSIVE OVERVIEW OF THE DATA ACQUISITION

The project commenced with collaborative discussions with officials from the GDOT, who provided a list of eight RCUT sites, detailed in **Table 2**. We initiated the analysis with a preliminary crash assessment, followed by an in-depth review focusing on RCUTs with significant crash histories. GDOT also provided the near-miss camera footage for certain RCUT sites, offering a substantial dataset that enabled us to analyze vehicle gap times. Below is an overview of the data acquisition methodology and its objectives:

**Crash Analysis Using Numetric by AASHTOware**

Numetric is a robust, cloud-based traffic safety analytics platform developed by AASHTOware. It provides access to crash data derived from police reports, facilitating comprehensive analysis of crash histories at various intersections. For this study, we utilized Numetric to examine the crash data of all eight RCUT sites, with a particular emphasis on incidents occurring at U-turns. However, the platform does not specifically identify crashes related to sight distance issues at U-turns. Consequently, we manually reviewed crash narratives for each incident near the U-turns to identify potential sight distance concerns.

While Numetric offered valuable crash data, including metrics such as crash rates, EPDO scores, and severity classifications, it presented certain limitations:

1) Lack of RCUT-Specific Data: Numetric specialized database primarily focuses on conventional intersections and does not include tools or databases tailored for RCUT intersections.

2) Absence of U-Turn and Sight Distance Filters: The platform lacks specific filters to distinguish crashes related to U-turn maneuvers or those caused by sight distance issues.

Despite these limitations, Numetric comprehensive crash data provided a solid foundation for the analysis, as shown in **Figure 14.**

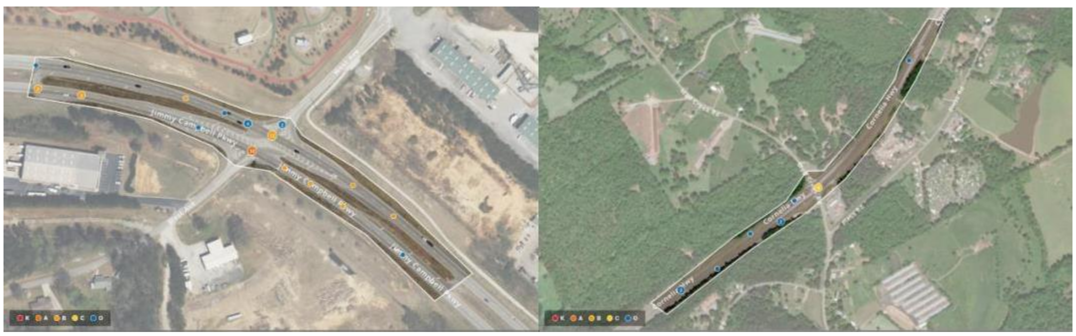


**Figure 14. Screenshot. Snippet of RCUT Intersection Crash Study and Its Severity Using Numetric.**

**Gap Time Measurement Using GDOT Camera Footage**

The near-miss camera footage cover various RCUT intersections, each spanning approximately 12-hour periods, as shown in **Figure 15**. These recordings captured vehicle movements at U-turn and left-turn intersections, allowing us to measure gap times. Gap time was measured by recording the duration from when a stopped vehicle began to move until it completed the U-turn. We excluded data from vehicles that did not stop before performing the U-turn, as their maneuver did not align with the proposed methodology.


**Figure 15. Screenshot. Sample Camera Footage Used for Gap Time Analysis.**

The camera footage offered a substantial amount of data, reflecting varying traffic conditions throughout the day. This enabled the model to account for diverse traffic scenarios. However, the footage had limited clarity (resolution) of major road traffic. The camera's resolution hindered the ability to assess the behaviour of vehicles on the major road, as their U-turning movements were unclear. To address these limitations, the Georgia Tech team collected drone footage at selected sites. The drone recordings, each lasting about 20 minutes, were captured at different locations and times of day to provide diverse perspectives. This supplementary data offered clearer insights into major road traffic behaviour and enhanced the understanding of interactions between major road vehicles and those performing U-turns.

## CRASH ANALYSIS FOR U-TURNS AT THE PROVIDED RCUT LOCATIONS

This section provides a detailed crash analysis of RCUT sites, focusing on crashes at their U-turns. We conducted a historical crash data analysis using Numetric to identify crashes at existing GDOT RCUT U-turn locations and study their characteristics. The outcomes of this analysis helped improve the sight distance model and validate the UTSD model. We examined the causes of U-turn crashes and explore potential improvements to enhance safety at RCUT intersections. To support our study, we also used Google Earth PRO for street views and elevation profiles.

**Preliminary Analysis**

In the first step of the study, we conducted a preliminary analysis of the crash data for eight RCUTs using the crash overview data. Referring to the Nomenclature in Table 1, RCUT 1 had two crashes at the U-Turn, one of which indicated of a potential sight distance issue. RCUT 3 recorded three U-turn crashes, two due to driver judgement error, and one potentially linked to sight distance. RCUT 4, which had video footage, revealed one crash potentially related to sight distance and another caused by driver judgement error (mentioned in renarrative). RCUT 2, RCUT 5, RCUT 6, RCUT 7, and RCUT 8 reported no U-turn crashes.

**Detailed Analysis**

From the preliminary analysis, we identified potential sight distance issues at RCUTs located at sites one, three and four. Our further study focused on investigating the causes of crashes at these three intersections.

*1)* **RCUT Site 1** - *Jimmy Campbell Parkway (US-278) @ S Main St/West Ave, Dallas, Georgia (GDOT District 6)*

Located at coordinates 33°54'54.1"N, 84°50'43.6"W, the RCUT was likely installed by 2018 (based on historical data from Google Earth) and has an Annual Average Daily Traffic (AADT) of 12,900 vehicles. The intersection showed a significant reduction in crash fatalities overall. A key crash narrative (from Numetric) indicated that the driver claimed, *"he was traveling in the right-hand lane of S.R. 6 East Bound when Vehicle #1 came out of nowhere in front of him."* This suggests several potential causes:

Potential Cause 1 - Lack of Stopping Sight Distance.

While the crash narrative suggests a vehicle appeared suddenly, the U-turn location is at the start of a horizontal curve. The sight distance measured above 800 ft, which meets the minimum design SSD per AASHTO Table 3-1, ruling out a lack of sight distance.

Potential Cause 2 - Driver Error.

As no underlying causes proved to be due to design issues, the most probable cause is driver error, likely due to poor judgment.

Therefore, after a thorough analysis, the most likely cause of the crashes appears to be driver error.

*2)* **RCUT Site 3** - *US 129/SR 11 @ Old Swimming Pool Rd, Jackson (Jefferson County), GA 30549 (GDOT District 1)*

Located at coordinates 34°06'45.8"N, 83°35'54.6"W, this RCUT was installed in December of 2021 and has an Annual Average Daily Traffic (AADT) of 12,650 vehicles. A key statement from the crash narrative (from Numetric) was: *"...he was coming over the crest of the hill, saw Unit 1 in the roadway, and was unable to steer around it."* This suggests two potential causes:

Potential Cause 1 - Lack of Stopping Sight Distance.

The mainline driver was unable to see the U-turning vehicle due to a crest in the road. The street view of the location also suggests a limited stopping sight distance.

Furthermore, a cursory view of the road's crest was conducted using Google Earth to examine the terrain. As shown in the **Figure 16**, the elevation profile shows the elevation profile of the road, with the red arrow on the map corresponding to the maximum elevation point (displayed by red line on plot). The RCUT is situated at the end of a vertical crest, and the analysis reveals a sight distance less than 500 feet with an elevation of 16 feet at the crest, which does not seem to be sufficient for this crash case.


**Figure 16. Screenshot. Elevation Profile of Road.**

<u>Potential Cause 2 -</u> Driver Error

Driver error remains a possibility, as no similar crashes have been reported at this location.

Therefore, the most likely cause of the crash appears due to the lack of sight distance due to vertical crest, but driver error cannot be ruled out.

3) **RCUT Site 4** - *SR 365 & Mud Creek Rd, Hall County, GA 30510 (GDOT District 1)*

Situated at coordinates 34°26'09.7"N, 83°37'54.7"W, this RCUT was installed on June 6, 2024, with an Annual Average Daily Traffic (AADT) of 12,650 vehicles. The crash narrative (from Numetric) revealed that the driver did not see oncoming traffic when making the U-turn and continued into the path of another vehicle. This suggests two potential causes:

Potential Cause 1 - Lack of U-turn Sight Distance.

The driver failed to see approaching traffic, which could be due to a curve near the U-turn. However, the RCUT is situated at the end of a straight road, and the sight distance exceeds 800 feet, ruling out this possibility.

Potential Cause 2 - Driver Error.

The most likely cause appears to be driver error, as there seems to be no apparent sight distance issues at this location.

Therefore, after a thorough analysis, the most likely cause of the crashes appears to be driver error.

**Table 3** summarizes the outcome of the crash analysis study. For better interpretability, street view snippets related to the studied RCUTs are attached in Appendix B. RCUT 3 can be used for comparison of our UTSD model.

**Table 3. Summary of RCUT Crash Analysis.**

| RCUT Location | Potential Site Distance Issue | Likely Cause of Crashes |
|---|---|---|
| RCUT 1 | No | Driver Error |
| RCUT 3 | Yes | Limited Stopping Sight Distance |
| RCUT 4 | No | Driver error |

# CHAPTER 5. RESULTS AND OUTCOMES

This section presents the conclusive findings of our research and outlines the proposed UTSD values, as recommended by the Georgia Tech research team, to facilitate safer road designs.

## U-TURNING TIME AND ACCELERATING

**Table 4** presents the average U-turning times derived from video footage provided by GDOT. These measured times represent the duration required for a vehicle to make the U-turn maneuver, starting from a complete stop to the point where the vehicle is parallel to the major road lane.

**Table 4. Measured U-turning Time for Passenger Cars from a Complete Stop.**

| Maneuver Type | U-turning Time ($t_u$) |
|---|---|
| 90-degree like U-turn | 4.25 sec |
| 180-degree like U-turn | 5.8 sec |

**Table 5** presents the accelerating distances extracted from **Figure** 12.

**Table 5. Accelerating Distances for Different Roadway Speeds, Extracted from AASHTO Acceleration Charts.**

| Design Speed (mph) | 70% Speed (mph) | Accelerating Distance (ft) |
|---|---|---|
| 15 | 10.5 | 40 |
| 20 | 14 | 50 |
| 25 | 17.5 | 60 |
| 30 | 21 | 100 |
| 35 | 24.5 | 150 |
| 40 | 28 | 200 |
| 45 | 31.5 | 255 |
| 50 | 35 | 310 |
| 55 | 38.5 | 400 |
| 60 | 42 | 460 |
| 65 | 45.5 | 600 |
| 70 | 49 | 780 |
| 75 | 52.5 | 820 |
| 80 | 56 | 1000 |

Accordingly, all UTSD tables have been constructed using these U-turning times and accelerating distances as a baseline to ensure consistency design applications. An illustrative example demonstrating the application of these benchmark values in a real-world context is provided in Appendix B below

## UTSD FOR 90-DEGREE LIKE U-TURNS

Our analysis indicates that at RCUT intersections with broader median nose (separator), closely resembles a 90-degree left turn (typically median nose widths greater or equal than 14 feet). Observations revealed that vehicles executing U-turns at these locations required less time to complete the maneuver and were able to accept shorter gaps in traffic.

From the camera footage analysed, the average of U-turning time was found to be 4.25

seconds. Utilizing the intersection sight distance equation, we can compute the U-turning Sight Distance for various design speeds. For instance, at a design speed of 45 mph:

$$\text{U-turning Sight Distance} = 1.47 \times 45 \times 4.25 \approx 281 \text{ (ft)}$$

However, this value alone can't meet the requirements of stopping sight distance of 45 mph (360 ft). In addition to the previously discussed U-turn maneuvering distances, the accelerating distance corresponding to the respective design speeds has been derived from **Figure** 12. The methodology for calculating accelerating distance is detailed in Appendix A. By aggregating the U-turn maneuvering distance and accelerating distance, **Table 6** presents a comprehensive summary of the total design sight distance for common design speeds utilized in roadway design.

**Table 6. UTSD Chart for 90-degree U-turns.**

| Design Speed (mph) | Safe Stopping Distance (ft) | U-Turn Sight Distance (ft) | | | |
|---|---|---|---|---|---|
| | | U-turning Sight Distance | Accelerating Distance | Total Sight Distance | Design Sight Distance (ft) |
| 15 | 80 | 93.71 | 40 | 133.71 | 135 |
| 20 | 115 | 124.95 | 50 | 174.95 | 175 |
| 25 | 155 | 156.19 | 60 | 216.19 | 220 |
| 30 | 200 | 187.43 | 100 | 287.43 | 290 |
| 35 | 250 | 218.66 | 150 | 368.66 | 370 |
| 40 | 305 | 249.90 | 200 | 449.90 | 450 |
| 45 | 360 | 281.14 | 255 | 536.14 | 540 |
| 50 | 425 | 312.38 | 310 | 622.38 | 625 |
| 55 | 495 | 343.61 | 400 | 743.61 | 745 |
| 60 | 570 | 374.85 | 460 | 834.85 | 835 |
| 65 | 645 | 406.09 | 600 | 1006.09 | 1010 |
| 70 | 730 | 437.33 | 780 | 1217.33 | 1220 |

Note: For trucks use a correction factor from the table below multiplying with the total sight distance listed on the above table.

**Table 7. Correction Factor for Trucks.**

| Vehicle Type | Correction Factor |
|---|---|
| Passenger Car | 1 |
| Single-Unit Truck | 1.27 |
| Combination Truck | 1.53 |

## UTSD FOR 180-DEGREE LIKE U-TURNS

Our study indicates that at RCUT intersections with narrower median noses, vehicles initiating U-turns often begin the maneuver in a parallel orientation to the major roadway. This configuration necessitates a more gradual steering input and a longer U-turn maneuver distance, mimicking a 180-degree turn (typically median nose widths less than 14 feet), thereby increasing the time required to complete the U-turn maneuver. Consequently, vehicles cannot accept shorter gaps in opposing traffic.

This behavior is particularly evident in urban settings where median nose widths are constrained. Analysis of camera footage revealed that the average U-turning time for these maneuvers was approximately 5.8 seconds. The U-turn maneuver time and the accelerating distance calculation procedure are similar to the steps listed in section 5.2. **Table 8** summarizes the UTSD for U-turns with narrower median noses.

**Table 8. UTSD Chart for 180-degree U-turns.**

| Design Speed (mph) | Safe Stopping Distance (ft) | U-Turn Sight Distance (ft) | | | |
|---|---|---|---|---|---|
| | | U-turning Sight Distance | Accelerating Distance | Total Sight Distance | Design Sight Distance (ft) |
| 15 | 80 | 127.9 | 40 | 167.9 | 170 |
| 20 | 115 | 170.5 | 50 | 220.5 | 225 |
| 25 | 155 | 213.2 | 60 | 273.2 | 275 |
| 30 | 200 | 255.8 | 100 | 355.8 | 360 |
| 35 | 250 | 298.4 | 150 | 448.4 | 450 |
| 40 | 305 | 341 | 200 | 541 | 545 |
| 45 | 360 | 383.7 | 255 | 638.7 | 640 |
| 50 | 425 | 426.3 | 310 | 736.3 | 740 |
| 55 | 495 | 468.9 | 400 | 868.9 | 870 |
| 60 | 570 | 511.6 | 460 | 971.6 | 975 |
| 65 | 645 | 554.2 | 600 | 1154 | 1155 |
| 70 | 730 | 596.8 | 780 | 1377 | 1380 |

Note: For trucks use a correction factor from the table below multiplying with the total sight distance listed on the above table.

**Table 9. Correction Factor for Trucks.**

| Vehicle Type | Correction Factor |
|---|---|
| Passenger Car | 1 |
| Single-Unit Truck | 1.27 |
| Combination Truck | 1.53 |

## GEOMETRIC DESIGN

This subsection outlines key geometric design elements relevant to RCUT intersection U-turns, based on observational data and supplementary literature review. The recommended UTSD values are contingent upon specific intersection configurations. It is imperative to consider these factors when applying the UTSD equation to ensure optimal safety outcomes. For U-turns located at intersections with on-coming vehicles, we suggest configurations including offset design, median width and opening, provision of loons, and the effect of grade on vehicle performance.

1) **Offset Design:** Offset design refers to the lateral positioning of opposing left-turn lanes at median crossovers and can be classified into negative, zero, or positive offsets. A negative offset occurs when opposing turn lanes are shifted away from one another, while a positive offset brings them closer together. A zero offset implies direct alignment of the opposing lanes. The RCUT sites evaluated in this study don't have opposing median turn lane, so no significant cases of positive or negative offsets were encountered; therefore, a literature review was conducted to inform design recommendations. A key study by Hutton et al. (2015), using data from the Strategic Highway Research Program 2 (SHRP 2) Naturalistic Driving Study (NDS), examined the relationship between left-turn lane offset and driver gap acceptance behavior. The research employed a linear regression model to assess gap length as a function of offset under both blocked and unblocked sight conditions, with offset values ranging from -29 feet to +6 feet.

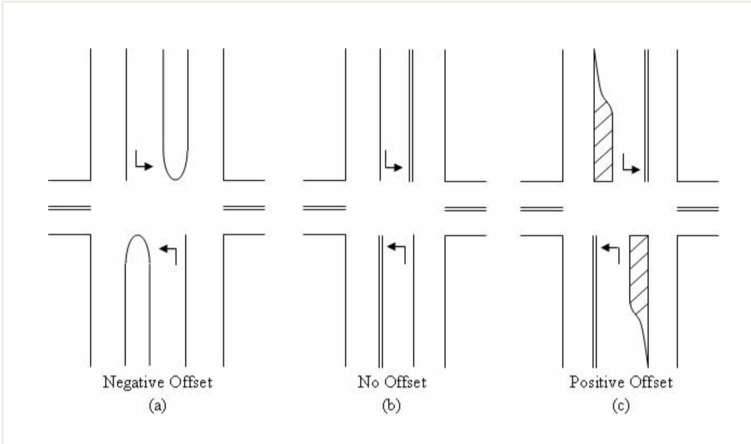



**Figure 17. Graph. Different Types of Offset: (a) Negative offset, (b) No Offset, (c) Positive Offset. (AASHTO, 2018)**

The study concluded that negative offsets were associated with the longest gap acceptance lengths, indicating that sight distances were more restricted. Drivers were notably less inclined to accept a gap when the view of oncoming traffic was blocked by an opposing left-turning vehicle. The study found that the riskiest left-turn maneuvers occurred at negative-offset configurations, due to the obstruction of oncoming traffic. Based on these findings, the study recommends avoiding negative offsets and suggests that zero or positive offsets are preferable as they enhance sight distance and improve safety.

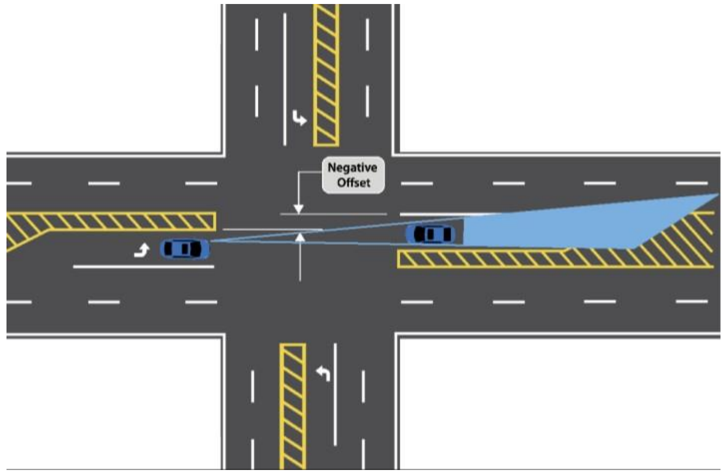



**Figure 18. Graph. Sight line Obstruction Depicted for A Negative Offset.**

2) **Median Width Design:** The Green Book includes design guidance for U-turn maneuvers, which provided minimum median widths required to accommodate U-turns for different design vehicles. This table as shown in **Figure 19** offered valuable insight into the relationship between median width, vehicle type, and turning feasibility.

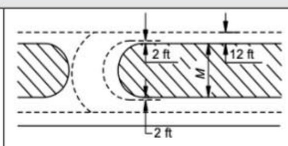
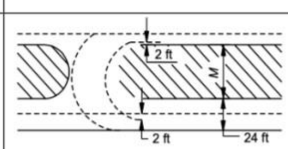
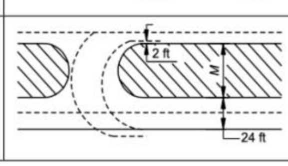
| U.S. Customary | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Type of Maneuver | | M—Minimum Width of Median (m) for Design Vehicle | | | | | | |
| | | P | WB-40 | SU-30 | BUS | SU-40 | WB-62 | WB-67 |
| | | Length of Design Vehicle (ft) | | | | | | |
| | | 19 | 50 | 30 | 40 | 40 | 63 | 68 |
| Inner Lane to Inner Lane |  | 30 | 61 | 63 | 63 | 76 | 69 | 69 |
| Inner Lane to Outer Lane |  | 18 | 49 | 51 | 51 | 64 | 57 | 57 |
| Inner Lane to Shoul-der |  | 8 | 39 | 41 | 41 | 54 | 47 | 47 |

**Figure 19. Table. Minimum Width of Median. (AASHTO, 2018)**

Given the increasing use of U-turn and RCUT designs in practice, future research can focus on identifying the most practical and economical median width requirements for different vehicle classes, including passenger cars and various truck configurations. Further investigation is also needed to quantify how median width influences two-stage U-turn maneuvering behavior and the associated U-turning time required under real-world operating conditions.

3) **Median Opening Design:** It is the median allowing vehicles to make crossing or turning maneuvers. Visual assessments of RCUT locations demonstrated that wider median openings facilitated easier maneuver for larger vehicles, allowing them to comfortably position their vehicles for U-turns without encroaching on adjacent lanes. From the footage analysis, it is recommended that sufficient width should be maintained in median openings to ensure maneuverability especially for locations that facilitate trucks.

4) **Loon:** A loon is an expanded paved area opposite a median crossover (depicted in **Figure 20).** The purpose of a loon is to provide additional space for vehicles to complete their turning maneuvers when the median separator itself is too narrow. Field observations revealed that loons helped in accommodating the wider turning paths of such vehicles. The provision of loons is therefore highly recommended in locations where the median is too narrow and locations where a higher frequency of commercial vehicle traffic is anticipated.

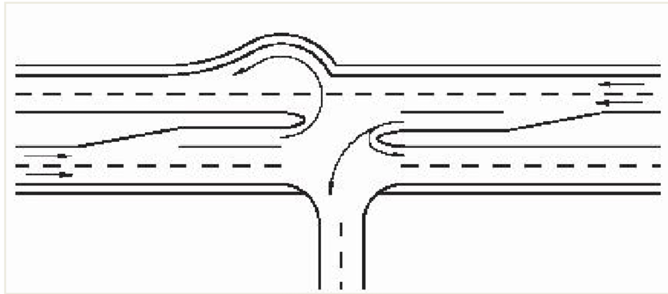


**Figure 20. Graph. Loon (expanded paved area) on A U-turn. (Potts, 2004)**

5) **Effect of grade:** Grade refers to the longitudinal slope of the road, expressed as a percentage. It represents the degree of incline or decline along the direction of travel. A positive grade indicates an uphill slope, while a negative grade denotes a downhill slope. The RCUT locations included in the study generally featured grades within ±2%, and thus no substantial grade-related impacts were recorded. However, grade remains a relevant design factor, particularly due to its influence on vehicle acceleration and deceleration, which directly affects sight distance requirements. The AASHTO Green Book provides grade adjustment factors in Table 9-5 (depicted in **Figure 21**), which should be applied to correct sight distance requirements under uncontrolled or yield-controlled conditions. This correction factor is applicable to RCUT U-turn movements as it matches the grade correction criteria from AASHTO Greenbook and should be incorporated during the design phase to ensure safe maneuvering across varied terrain conditions.

| U.S. Customary | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Approach Grade (%) | Design Speed (mph) | | | | | | | | | | | | | |
| | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 60 | 65 | 70 | 75 | 80 |
| −6 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 |
| −5 | 1.0 | 1.0 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.2 | 1.2 | 1.2 | 1.2 |
| −4 | 1.0 | 1.0 | 1.0 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 |
| −3 to +3 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 | 1.0 |
| +4 | 1.0 | 1.0 | 1.0 | 1.0 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 |
| +5 | 1.0 | 1.0 | 1.0 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 |
| +6 | 1.0 | 1.0 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 | 0.9 |

**Figure 21. Table. Adjustment Factors for U-turn Sight Distance Based on Approach Grade.**

## MODEL COMPARISON

To ensure the reliability and applicability of the proposed UTSD model, a multi-step comparison process was undertaken. This included comparisons with existing models used by state DOTs, an assessment of alignment with AASHTO guidelines for similar maneuver, and a review of crash data from real-world RCUT locations.

**Table 10. Comparison of Sight Distance Values of Common Roadway Speeds Between FDOT, La DOTD, Proposed Sight Distance Model and AASHTO Case B1.**

| Speed | FDOT Model | La DOTD Model (AASHTO Case F) | Proposed Model (90 degree) | Proposed Model (180 degree) | AASHTO Case B1 |
|---|---|---|---|---|---|
| **45 mph** | 830 ft | 365 ft | 540 ft | 640 ft | 500 ft |
| **55 mph** | 1040 ft | 445 ft | 745 ft | 870 ft | 610 ft |

### Comparison of our UTSD model with other State DOT Models

The UTSD values generated by our model were compared with those from the FDOT and the La DOTD. As presented in **Table 10**, our model produced sight distance values that are more conservative than those recommended by La DOTD, yet significantly more realistic and achievable than the considerably higher values proposed by FDOT. This comparison demonstrates that our model strikes a balance between safety and practical design feasibility.

### Alignment with AASHTO Gap Time Guidelines for Intersections

To further assess the validity of our model, we compared its recommended gap times with those outlined in the AASHTO Green Book for similar intersection maneuvers. Specifically, Case B1 (left turn from a stop) was used as benchmarks. As shown in **Table 10**, our model consistently yielded longer sight distance values, which is expected, given that U-turns generally require more time and space to complete than traditional left turns. The alignment with these established gap time scenarios reinforces the logic and conservativeness of our methodology.

### Analysis of U-Turn Sites with Crash

A crash analysis was conducted at one RCUT location with a history of incidents potentially attributable to limited sight distance. Observational and video data suggested that a sight distance exceeding 500 feet would have been appropriate at this site. Our model, when applied to this location, recommended a sight distance of 540 feet, which aligns with the observed need and indicates the model's ability to reflect real-world safety considerations. This case reinforces the practical validity of the model, especially in identifying locations that may benefit from enhanced sight distance for safety performance.

# CHAPTER 6. FINDINGS AND RECOMMENDATIONS

This chapter summarizes the key findings of the study and provides recommendations for future research based on observed limitations and emerging questions identified during the analysis.

## RESEARCH FINDINGS

1) The study concluded that the basic intersection sight distance equation, expressed as ISD = 1.47 × $t_{ut}$ × $V$, is applicable for calculating U-turn Sight Distance. This rationale is grounded in the concept that the time required for a turning vehicle to complete its maneuver should allow it to safely clear the intersection before an approaching vehicle on the major road reaches the same point. The same principle holds true for U-turn movements.

2) It was determined, given the data constraints, the most appropriate method for estimating the total maneuver time includes both the actual U-turn maneuvering time and the distance required for the turning vehicle to accelerate to 70% of the major road's operating speed. This approach offers a more complete framework for gap time assessment by incorporating driver comfort, speed consistency, and major road performance into the design. In ideal conditions, this method ensures that major-road vehicles are not forced to decelerate below 70% of their initial speed (according to the Green Book Chapter 9, page 9-43, Section 9.5.3.2.1), thereby promoting smoother traffic operations.

3) Analysis of near-miss camera video footage indicated a clear relationship between

median nose width and U-turn performance. Specifically, vehicles at wider median noses, where they have storage in the median to position themselves perpendicular to traffic and make a 90 degree turn, completed U-turns in approximately 4.25 seconds; while for narrower median noses, where vehicles can not position themselves perpendicular to traffic and take a 180 degree turn, the u-turning time increased to about 5.8 seconds. .

4) Literature review was conducted concerning the influence of left-turn lane offset. Negative offsets were found to obstruct sightlines for turning vehicles and increase driver hesitation, resulting in longer wait times and higher risk during U-turn maneuvers. These findings support the recommendation to avoid negative offsets and favor zero or positive offset designs.

5) For locations where truck U-turns are anticipated, the study recommends using a correction factor derived from the ratio of maneuver times for trucks and passenger cars as presented in the AASHTO Green Book. Additionally, the provision of wider median openings and the inclusion of loons are strongly advised to accommodate the larger turning radius and longer maneuver time required by trucks.

6) Our model stands more conservative than the model designed by La DOTD but also provides significantly smaller and realistic values compared to the FDOT model. From comparison with case B1 type of intersection maneuvers from AASHTO Greenbook, we found that our sight distance values were greater than that of the listed maneuvers, and this is the expected values, as U-turns take longer than left turns. Lastly, our sight distance model showed to provide larger recommended sight

distance in locations identified with crashes due to potential sight distance issues, hence validating the robustness and the realistic values of our model.

7) A comparative evaluation of our proposed sight distance model against established standards revealed important insights into its performance. Specifically, our model was found to be more conservative than the model used by the Louisiana Department of Transportation, yet it yielded more realistic and practically achievable values than the model adopted by the Florida Department of Transportation. When benchmarked against *Case B1* (left turn from a stop) from the AASHTO Green Book, our model consistently produced greater sight distance values. This outcome aligns with expected behavior, as U-turn maneuvers generally require more time and space than left turns. Furthermore, our model recommended longer sight distances at locations where crash data suggested a history of visibility-related incidents, potentially due to shorter sight distance. This correlation supports the validity and robustness of our model and highlights its potential in enhancing safety outcomes through more accurate and context-sensitive sight distance estimation.

## RECOMMENDATIONS FOR FUTURE STUDY

1) While the current study utilized acceleration values from standard AASHTO charts, it is recognized that these may no longer reflect actual vehicle performance due to improvements in vehicle design and engine efficiency. Although these charts offer a conservative basis for design, future studies should aim to develop updated acceleration curves based on empirical field data to better represent real-world

conditions.

2) Our study had limited data on commercial vehicle movement, and only one RCUT U-turn had truck access. This limited the generalizability and statistical strength of our findings related to commercial U-turn behavior. Furthermore, no established reliable acceleration charts currently exist for trucks. To address this gap, future research should undertake focused field studies to observe and quantify commercial vehicle U-turn dynamics, leading to more precise design standards and guidelines.

3) While beyond the primary scope of this project, preliminary drone footage collected by the GT research team revealed a potential safety concern at select RCUT sites. Specifically, vehicles from minor roads attempting to merge into the U-turn lane and execute a U-turn onto the major road were observed to face prolonged waiting times and, in some cases, performed unsafe maneuvers. These incidents were attributed to insufficient space for acceleration, merging, and deceleration. This issue highlights a design deficiency in median length and merging area provisions and points to the need for dedicated design criteria to address these challenges.

## APPENDIX A - EXAMPLE CALCULATIONS FOR UTSD

For a U-turn with median nose width of 15 ft placed at a roadway with speed of 50 mph and a uphill grade of + 4%, the U-turn sight distance is:

Step 1: Check for median nose width

Referring to **Table 4**, the median nose width is greater than 14 ft. Hence the U-turning time will be 4.25 seconds.

Step 2: Sight distance Required for U-turning

Using the equation $UTSD = 1.47 \times t_u \times V$, we get

UTSD = 1.47 x 4.25 x 50

= 312.38 ft

Step 3: Find the corresponding accelerating distance

From **Table 5**, the corresponding accelerating distance for 50 mph (or 70% of 50 mph, 35mph) is 310 ft.

Step 4: Add the U-turning distance and accelerating distance for total sight distance.

UTSD = 312.38 ft + 310 ft

= 622.38 ft

Step 5: Apply the required corrections.

Referring to **Figure 21**, for 4% uphill grade at a 50-mph road, Grade correction factor is 0.9

UTSD = 0.9 x 622.38 ft

Therefore, the corrected sight distance is 560.14 ft (or ≈ 565 ft)

(Optional: In case of design for single unit trucks, refer **Table 7**. Correction factor is 1.27. Hence UTSD = 560.14 x 1.27 = 711.38 ft ≈ 712 ft.)

## APPENDIX B - HOW DOES OUR METHOD IMPROVES UPON EXISTING PRACTICES?

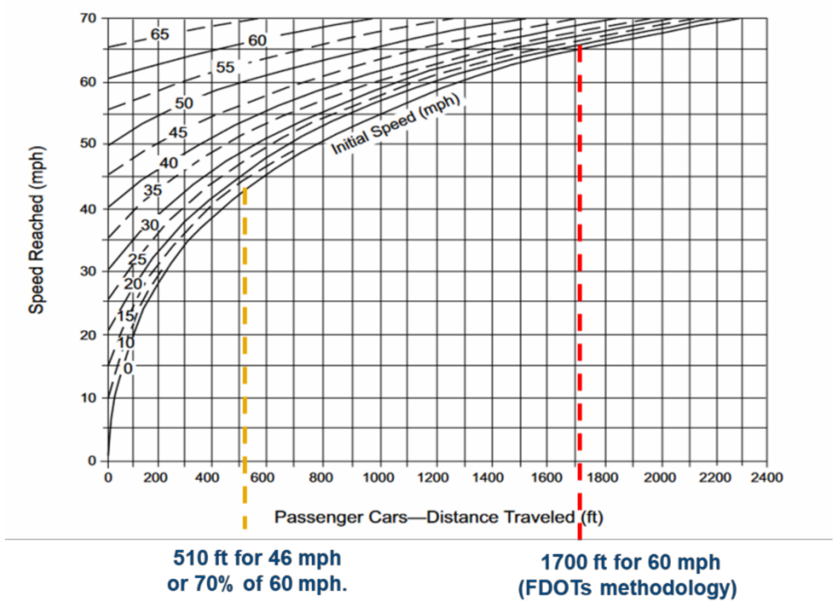



**Figure 22. Illustration. Comparison of Accelerating Distances between Proposed Model and FDOTs Model.**

The proposed UTSD methodology offers a significant improvement over existing practices, particularly when compared to the approach used by the Florida Department of Transportation (FDOT). FDOT's method relies on the full acceleration length required for a vehicle to reach highway speed, which often results in overly conservative and impractically long sight distance requirements. Such estimates can pose design and implementation challenges, especially in constrained urban or semi-urban environments. In contrast, our method adopts a more context-sensitive approach by using 70 percent of the major road's operating speed as the benchmark for acceleration. This adjustment yields more realistic and attainable sight distance values while still maintaining a high standard of safety. Importantly, this approach is consistent with the guidance provided in the AASHTO Green Book, which states that "most major-road drivers should not need to reduce speed to less than 70 percent of their initial speed." By aligning with this principle, our method balances operational efficiency with safety, and provides a practical, evidence-based framework for RCUT design.

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