CUTR RESEARCH

**Final Report**

**BDV25-977-26**

# Understanding Interactions between Drivers and Pedestrian Features at Signalized Intersections – Phase 2

**PREPARED FOR**
**Florida Department of Transportation**

**August 2017**

Center for Urban Transportation Research
University of South Florida
4202 E. Fowler Ave., CUT100, Tampa, FL 33620-5375

# Understanding Interactions between Drivers and Pedestrian Features at Signalized Intersections – Phase 2

**Final Report**

**FDOT BDV25-977-26**

Prepared for:

**Florida Department of Transportation**

Joe Santos, P.E., Project Manager

Darryll Dockstader, Co-Project Manager

Prepared by:

**USF Center for Urban Transportation Research**

Pei-Sung Lin, Ph.D., P.E., PTOE

Achilleas Kourtellis, Ph.D.

Zhenyu Wang, Ph.D.

Cong Chen, Ph.D.

Rui Guo, Ph.D.

**August 2017**

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# UNIT CONVERSION TABLE

**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 |

| SYMBOL | WHEN YOU KNOW | MULTIPLY BY | TO FIND | SYMBOL |
|---|---|---|---|---|
| **AREA** | | | | |
| **in$^2$** | squareinches | 645.2 | square millimeters | mm$^2$ |
| **ft$^2$** | squarefeet | 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$^2$ |

| SYMBOL | WHEN YOU KNOW | MULTIPLY BY | TO FIND | SYMBOL |
|---|---|---|---|---|
| **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$^3$ | | | | |

| SYMBOL | WHEN YOU KNOW | MULTIPLY BY | TO FIND | SYMBOL |
|---|---|---|---|---|
| **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") |

| SYMBOL | WHEN YOU KNOW | MULTIPLY BY | TO FIND | SYMBOL |
|---|---|---|---|---|
| **TEMPERATURE (exact degrees)** | | | | |
| **°F** | Fahrenheit | 5 (F-32)/9<br>or (F-32)/1.8 | Celsius | °C |

| SYMBOL | WHEN YOU KNOW | MULTIPLY BY | TO FIND | SYMBOL |
|---|---|---|---|---|
| **ILLUMINATION** | | | | |
| **fc** | foot-candles | 10.76 | lux | lx |
| **fl** | foot-Lamberts | 3.426 | candela/m$^2$ | cd/m$^2$ |

| SYMBOL | WHEN YOU KNOW | MULTIPLY BY | TO FIND | SYMBOL |
|---|---|---|---|---|
| **FORCE and PRESSURE or STRESS** | | | | |
| **lbf** | poundforce | 4.45 | newtons | N |
| **lbf/in$^2$** | poundforce per square inch | 6.89 | kilopascals | kPa |

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16. Abstract

Pedestrian safety is one of the highest priorities in the Florida Department of Transportation (FDOT). Since 2011, FDOT has actively researched, developed, and implemented countermeasures to improve pedestrian safety and reduce pedestrian-related fatalities, injuries, and crashes. This research used the second Strategic Highway Research Program (SHRP2) Naturalistic Driving Study (NDS) data and Roadway Information Database (RID) to better understand the interactions between drivers and pedestrian features at signalized intersections. The research team identified and quantified these interactions and developed implementable countermeasures to increase pedestrian safety at signalized intersections in Florida. Through the Phase 1 project, the researchers developed a research methodology, obtained initial research results, achieved a preliminary understanding of interactions between drivers and pedestrian features at signalized intersections, and also demonstrated the capability to effectively use the NDS and RID databases to study drivers' rates of compliance with pedestrian safety-related signage at signalized intersections. This Phase 2 project was built on the foundation of the Phase 1 project. The research team conducted a full-scale research and analysis with large sample data via the Phase 2 project and developed implementable countermeasures in engineering, education, and enforcement based on the results and findings from Phase 2 for future pilot and full implementations in Florida. This research also reached solid conclusions and recommendations. The results and findings of this project provide a clear insight into driver compliance rates with main pedestrian feature signs at signalized intersections and full support for recommended countermeasures for implementation to improve pedestrian safety at signalized intersections.

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# EXECUTIVE SUMMARY

## INTRODUCTION

According to the National Highway Traffic Safety Administration (NHTSA), Florida experienced serious pedestrian safety problems and had the second-highest pedestrian fatality rate among all U.S. states in 2014 and the highest rate from 2008–2011. One of Florida's highest priorities is investigating major contributing causes of pedestrian fatalities and developing effective countermeasures to significantly improve pedestrian safety. Additional statistics show that pedestrian crashes tend to be more concentrated at intersections.

The Strategic Highway Research Program 2 (SHRP2) Naturalistic Driving Study (NDS) recorded the driving behavior of a large sample of drivers in their personal vehicles, offering comprehensive naturalistic driving behavioral data for researching the interactions between drivers and various pedestrian features at selected signalized intersections through which they drove. The ultimate goal of this research project was to use the SHRP2 NDS and Roadway Information Database (RID) datasets to better understand the interactions between drivers and pedestrian features at signalized intersections and develop effective countermeasures to significantly increase pedestrian safety.

The research project aimed to investigate the effectiveness of four pedestrian features ("Stop Here on Red," "No Turn on Red," "Turning Vehicles Yield to Pedestrians," and "Right on Red Arrow after Stop" signs) used at signalized intersections that are directly related to pedestrian safety. Built on the foundation of the Phase 1 project (BDV25-977-16, Understanding Interactions between Drivers and Pedestrian Features at Signalized Intersections) and with a sufficient amount of data for research, results from the Phase 2 project provide detailed and more in-depth qualitative and quantitative analysis regarding driver demographic and risky/distractive behavior characteristics and offer researchers and FDOT managers a better understanding of the interactions between drivers and pedestrian features at signalized intersections. Based on the understanding of these interactions, effective and implementable countermeasures in engineering, education, and enforcement can be developed to increase driver compliance with pedestrian features and improve pedestrian safety in Florida.

## GOALS AND OBJECTIVES

The goals of this project were to conduct further research to better understand the interactions between drivers and pedestrian features at signalized intersections based on the foundation built in Phase 1 and to develop implementable countermeasures to increase driver compliance with pedestrian features in Florida based on research findings to reduce conflicts between vehicles and crossing pedestrians and improve pedestrian safety in the future.

The specific objectives of this project were to:

- Fully investigate and better understand the interactions between drivers and pedestrian features at signalized intersections using NDS and RID datasets.
- Produce statistically-significant and detailed findings.
- Recommend implementable countermeasures in engineering, education, and enforcement to improve pedestrian safety in Florida and in other states with similar problems.

## DATA USE AND PROCESSING

Data for the Phase 2 project was from the same datasets used in Phase 1, but a larger amount of data was needed in Phase 2, as was a large sample size with pedestrian presence. As such, a larger dataset was requested from Virginia Tech Transportation Institute (VTTI) to achieve statistically significant analysis.

### Tool Enhancement

Two data extraction and analysis tools—NDS Automatic Video Processing Tool (AVPT) and NDS Data Reduction and Analysis Tool (DRAT)—were developed in Phase 1 to produce the dataset for analysis from the NDS datasets. In Phase 2, these tools were enhanced to improve data reduction efficiency and accuracy based on the Phase 1 experience.

### NDS Automatic Video Processing Tool

The NDS Automatic Video Processing Tool (AVPT) was designed primarily to automatically detect and track pedestrians and automatically detect traffic signal indications in NDS videos. In Phase 2, several improvements were implemented to make the AVPT more robust, efficient, and accurate for actual use:

- Applied deblurring filters to aid in video sharpness and increase detection accuracy for low-resolution videos.
- Compared algorithms and functions to optimize possible configurations and outputs.
- Coded algorithms on OpenCV + CUDA platform by C++ to use GPU capability for dramatically increasing processing speed.

### NDS Data Reduction and Analysis Tool

The NDS Data Reduction and Analysis Tool (DRAT) was developed in Phase 1 to assist researchers in reviewing and analyzing NDS videos and sensor data. In Phase 2, the DRAT tool was upgraded to satisfy the needs of new data reduction procedure:

- Fine-tune user interface to allow faster reviewer input
- Add Google Maps links to validate site and pedestrian features

After data filtering and reduction, the research team reviewed 8,569 events (videos) at 99 sites, and data of 2,037 qualified events from feature sites were used in the analysis.

## DATA ANALYSIS METHODS

Cross-sectional analysis was used in this study to assess the safety effectiveness of the selected pedestrian features—the higher the proportion of compliant behaviors observed, the better the safety performance. A series of comparisons of the compliant behaviors was conducted between each feature group and its control group and between different driver characteristics (gender, age, education level, attention-deficit/ hyperactivity disorder [ADHD] level, and risk/distraction groups), and environmental features (event time, sign location) for each pedestrian feature. Chi-square tests were used to determine the significance of difference in proportion of compliant driver behaviors between groups. All hypothesis tests were conducted at a minimum confidence level of 90%.

In addition, a generalized linear mixed model (GLMM) model was used in this study to identify the significant factors affecting driver compliance behavior at pedestrian features and their individual and heterogeneous influence on driver compliance behavior distribution while holding other factors constant. The significance of factor influences was identified at 90% confidence level.

## RESEARCH RESULTS

Major findings of this Phase 2 project include the following:

- The proportion of compliant driver behaviors, defined based on the intention of the specific feature, is an effective measure of the interactions between drivers and pedestrian features. The “NO TURN ON RED” sign had the highest rate of compliance (90.9%), followed by “TURNING VEHICLES YIELD TO PEDESTRIANS” (85.7%), “STOP HERE ON RED” (74.5%), and “RIGHT ON RED ARROW AFTER STOP” (74.4%). All four features increased the likelihood of compliant behaviors compared to control groups.
- Regarding driver compliant behaviors by gender at feature sites for “STOP HERE ON RED” and “RIGHT ON RED ARROW AFTER STOP” signs, female drivers were less likely to comply than male drivers, and the differences were statistically significant. For the “NO TURN ON RED” feature, female drivers were more likely to comply with the feature than male drivers, and the difference was also statistically significant.
- Comparison of driver compliance behaviors by age at feature sites indicated that mid-age drivers (ages 25–59) had the highest compliance rates for “NO TURN ON RED,” “TURNING VEHICLES YIELD TO PEDESTRIANS,” and “RIGHT ON RED ARROW AFTER STOP” signs. Older drivers (ages 60+) had the highest compliance rates for “STOP HERE ON RED” signs and the lowest compliance rate for “NO TURN ON RED” and “RIGHT ON RED ARROW AFTER STOP” signs among all three age groups. Younger drivers had the lowest compliance rate for “STOP HERE ON RED” and “TURNING VEHICLES YIELD TO PEDESTRIANS” signs among all three age groups.

- Comparison of compliant behaviors by education level at feature sites showed that, overall, a higher education level led to a higher proportion of driver compliance behaviors at sites with pedestrian features.
- Comparison of compliant behaviors by ADHD level at feature sites showed that drivers without ADHD symptoms had a higher proportion of compliance than their counterpart groups.
- Comparison of compliant behaviors by sign locations at feature sites showed that overhead signs on signal mast arms or span wires produced a higher proportion of compliant behaviors than right side (roadside), and the difference is statistically significant at the 95% confidence level.
- Regarding impacts of pedestrian presence, drivers showed a much higher proportion of compliance at the feature sites than at the control sites (78.1% vs. 64.3%) when pedestrians were not present at intersections. This indicates that drivers most likely will comply with pedestrian features at feature sites even though there are no pedestrians present or drivers do not see them.
- From the perspective of consistency of driver compliance performance, male drivers demonstrated comparable proportions of compliant behaviors with pedestrian feature signs among age groups. Female drivers showed a larger variation for proportion of compliant behaviors among age groups. Younger (ages 16–24) female drivers exhibited the lowest proportion of compliant behaviors, at 73.3% overall compliance.
- Based on self-evaluation of risk and distraction levels, more female drivers were classified into the High Risk and High Distraction groups than male drivers. Younger drivers (ages 16–24) took significantly more risks than those in other age groups, and younger drivers (ages 16–24) and mid-age drivers (ages 25–59) were more likely to be distracted than older drivers (ages 60+). Older drivers (ages 60+) took significantly fewer risks and were less likely to be distracted than other drivers.
- From the perspective of impacts of driver risk and distraction characteristics on compliant behaviors:
    - At sites with a “STOP HERE ON RED” sign, drivers in the Low Risk or Low Distraction groups were more likely to comply with the sign than were those in the corresponding counterpart group.
    - At sites with a “NO TURN ON RED” sign, drivers in the High Risk and Low Risk groups produced comparable proportions of compliance. Drivers in the High Distraction group were significantly more likely to comply with the sign than drivers in the Low Distraction group. This is reasonable because highly-distracted drivers are more likely to become involved in secondary tasks, such as checking their cell

phones, eating, etc., and are more likely to stop at this sign to perform these activities while ensuring driving safety at the same time.

- At sites with a "TURNING VEHICLES YIELD TO PEDESTRIANS" sign, drivers in the Low Risk or Low Distraction groups were more likely to comply with the sign than those in the corresponding counterpart group.
- At sites with a "RIGHT TURN ON RED ARROW AFTER STOP" sign, drivers in the Low Risk group were more likely to comply with the sign than those in the High Risk group, but the difference was not significant. Drivers in the Low Distraction group were more likely to comply with the sign than those in the High Distraction group; the difference was statistically significant at a 90% confidence level.

## RECOMMENDATIONS

The major recommendations from this Phase 2 project are to implement recommended countermeasures via pilot studies, fine-tune the countermeasures based on the results of the pilot implementations, develop a future statewide implementation plan, and implement the finalized countermeasures statewide to improve pedestrian safety and reduce pedestrian-related fatalities, injuries, and crashes in Florida. Specific recommendations include the following:

- Select recommended countermeasures from this research project for pilot implementations at selected signalized intersections in the northern, central, and southern regions of Florida and evaluate the implementation results via before-and-after studies.
- Develop criteria and guidelines for site selection for the pilot implementations using crash history, vehicle and pedestrian volumes, and pedestrian crash type information and coordinate and obtain inputs from FDOT District offices to ensure local knowledge inclusion.
- Document the process, benefits, challenges, and solutions of the pilot implementations to benefit future statewide implementations.
- Enhance and finalize the countermeasures and implementation guidelines based on the results of the pilot implementations.
- Recommend FDOT Central Office and District offices to lead future statewide implementations after the pilot implementations, starting with signalized intersections with pedestrian safety problems and compliance issues.

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# 1. INTRODUCTION

Pedestrian safety is one of the highest priorities in the Florida Department of Transportation (FDOT). Since 2011, FDOT has actively researched, developed, and implemented countermeasures to improve pedestrian safety and reduce pedestrian-related fatalities, injuries, and crashes. This research was to use the second Strategic Highway Research Program (SHRP2) Naturalistic Driving Study (NDS) data and Roadway Information Database (RID) to understand the interactions between drivers and pedestrian features at signalized intersections. The ultimate goals of the research were to identify and quantify these interactions and develop implementable countermeasures to increase pedestrian safety at signalized intersections in Florida.

Through the Phase 1 project, researchers at the Center for Urban Transportation Research (CUTR) at the University of South Florida (USF) developed a research methodology, obtained initial research results, achieved a preliminary understanding of interactions between drivers and pedestrian features at signalized intersections, and demonstrated the capability to effectively use the NDS and RID databases to study driver compliance rates to pedestrian safety-related signage at signalized intersections. This Phase 2 project was built on the foundation of the Phase 1 project. The CUTR research team conducted a full-scale research and analysis effort with large sample data via the Phase 2 project and developed implementable countermeasures for future pilot and full implementations in Florida.

This chapter provides a background of the research project followed by a summary of findings from the Phase 1 project and describes the project goals and specific project objectives. Report organization is presented at the end of the chapter.

## 1.1. Background

Florida has experienced serious pedestrian safety problems and had the second-highest pedestrian fatality rate among all U.S. states in 2014 and the highest rate from 2008–2011 based on National Highway Traffic Safety Administration (NHTSA) Traffic Safety Facts annual reports (NHTSA, 2017). The 2016 edition of *Dangerous by Design* indicated that Florida topped the most dangerous list for walking in the U.S.; however, its statewide Pedestrian Danger Index (PDI) had declined by 5.8 points since 2011 due to statewide safety efforts (Smart Growth America, 2017). A variety of factors contribute to pedestrian crashes in Florida. One of the highest priorities for the Florida Department of Transportation (FDOT) is to investigate major contributing causes of pedestrian fatalities, injuries, and crashes and develop effective and implementable countermeasures to significantly improve pedestrian safety in Florida. Pedestrian safety at signalized intersections was one of major focuses of FDOT on reducing pedestrian related fatalities, injuries, and crashes in Florida.

The SHRP2 Implementation Assistance Program (IAP) was developed and launched in 2013 to help state departments of transportation (DOTs), metropolitan planning organizations (MPOs), and other interested organizations deploy SHRP2 Solutions. The SHRP2 IAP is sponsored by the

Federal Highway Administration (FHWA) and the American Association of State Highway and Transportation Officials (AASHTO). SHRP2 developed new and comprehensive data about what occurs in a vehicle before and during crashes and near-crash events. SHRP2 safety data consist of two large databases—the naturalistic driving study (NDS) database and the roadway information database (RID). An important IAP focus is from concept to countermeasure and research to deployment using the SHRP2 safety data. FDOT was among 10 State DOTs awarded implementation assistance for safety data in Phases 1 (pilot data analysis) and 2 (full data analysis).

The SHRP2-NDS recorded the driving behavior of a large sample of drivers in their personal vehicles and collected detailed RID to support various types of research. The SHRP2-NDS dataset includes comprehensive data from participants, vehicles, and trips. The NDS and RID datasets offer Florida project researchers a unique opportunity to investigate interactions between drivers and pedestrian features and develop effective and implementable countermeasures for signalized intersections.

Pedestrian features refer to pedestrian safety-related signs, vehicle stop bars, pedestrian crosswalks, pedestrian signals, traffic signals, and pavement markings at signalized intersections. The interactions between drivers and pedestrian features refer primarily to driver compliance with the intention of the pedestrian feature, specifically at signalized intersections.

Four major pedestrian features used at signalized intersections that are directly related to pedestrian safety. A description of the intention of and compliant behaviors for each pedestrian feature is shown in Table 1.

**Table 1 - Description of Intention and Compliant Behaviors for Each Pedestrian Feature**

| Feature Name | Feature Sign | Feature Intention | Compliant Behaviors |
|---|---|---|---|
| STOP HERE ON RED |  | Used to tell drivers to stop at stop bar where sign is installed to ensure everyone's safety; vehicles stopping at stop bar and not on crosswalk can avoid hitting pedestrians crossing at crosswalk. | Stop before stop line on red |
| NO TURN ON RED |  | Used primarily at intersections with higher number of conflicts between vehicles making right turn on red and vehicles or pedestrians crossing; especially in Florida, turning right on red is a major cause of pedestrian crashes at intersections. | Stop on red and wait for green signal |
| TURNING VEHICLES YIELD TO PEDESTRIANS |  | Informs turning vehicles making right or left turn at intersections to yield to crossing pedestrians; applies when traffic signal is red or green. | Yield to pedestrians on green or red |
| RIGHT ON RED ARROW AFTER STOP<br>+<br>Photo Enforced |  | Installed together in Tampa Bay to direct drivers to stop on red before making a right turn; usually coupled with red light cameras for enforcement; installed where there is higher number of violations of drivers not making stop on red before proceeding to make right turn. | Stop, observe, and turn on red |

### 1.2. Phase 1 Findings

The Phase 1 project provided the proof of the concept for its initial proposed methodology, developed preliminary analysis tools, conducted initial data analysis produced initial analysis results, and offered recommendations for the Phase 2 project. The major analysis results, findings and recommendations from the Phase 1 project are summarized below.

- The compliance rate of driver behaviors to the intention a pedestrian feature is an effective measure of the interactions between drivers and pedestrian features.
- The proposed methodologies in Phase 1were proved effective for the usage of the SHRP 2 NDS and RID databases to study interactions between drivers and pedestrian features at signalized intersections.
- The preliminary tools developed for NDS automatic video processing and NDS data reduction and analysis were promising and could be further enhanced in the Phase 2 project.
- Three features signs—“STOP HERE ON RED,” “NO TURN ON RED,” and “RIGHT ON RED ARROW AFTER STOP”—increased the likelihood of compliant behaviors when compared to those without such signs.
- Drivers had a much higher compliance rate at the feature sites than at the control sites when pedestrians were not present at intersections. The difference was statistically significant.
- Drivers were generally sensitive to pedestrian presence at both the feature sites and the control sites. Their compliance percentages for both groups were higher when pedestrians were present than those when pedestrians were absent.
- Drivers were more likely to comply with the feature at feature sites than at control sites when pedestrians were present However, there was no evidence to show the difference was statistically significant due to a small sample size.
- Based on self-evaluation, female drivers were significantly more likely to believe they are easily distracted when driving compared to male drivers. Older drivers (age 60+) believe they take significantly fewer risks and are less distracted than other drivers.
- Female drivers tended to comply more consistently with the pedestrian features than male drivers. Mid-age drivers tended to comply more consistently with the pedestrian features than others.
- The limited sample sizes may result in insignificant comparisons of compliance rates by driver characteristics (e.g., age, gender, risk and distraction levels). A larger sample size is expected to draw confident conclusions and obtain insight into compliance patterns by driver characteristics and pedestrian features.

- The Phase 2 study with a large sample size can result in development of implementable countermeasure to improve pedestrian and bicycle safety at signalized intersections.

The initial research results and preliminary findings offer valuable insight into the effectiveness of specific pedestrian features and the preliminary effect of drivers' characteristics on their compliance with individual pedestrian features.

## 1.3. Project Goals and Objectives

### *1.3.1. Project Goals*

The major goals of this Phase 2 project were to:

- Complete research based on the foundation built in Phase 1 to better understand the interactions between drivers and pedestrian features at signalized intersections.
- Develop implementable countermeasures based on research findings for future improvements to pedestrian safety at signalized intersections via the improvement of driver compliance with pedestrian features.

The first goal of this project was to conduct further research to better understand the interactions between drivers and pedestrian features at signalized intersections based on the foundation built in Phase 1. The second goal was to develop implementable countermeasures to increase driver compliance with pedestrian features based on research findings to improve pedestrian safety at signalized intersections in Florida, particularly to reduce conflicts between vehicles and crossing pedestrians and improve pedestrian safety at signalized intersections when the countermeasures are implemented in the future.

### *1.3.2. Project Objectives*

The specific project objectives of Phase 2 were to:

- Fully investigate and better understand the interactions between drivers and pedestrian features at signalized intersections using NDS and RID datasets.
- Produce tangible outcomes and detailed findings.
- Recommend implementable countermeasures in engineering, education, and enforcement regarding pedestrian features at signalized intersections to improve pedestrian safety in Florida and in other states with similar problems.

The first objective was to complete data acquisition from the Virginia Tech Transportation Institute (VTTI), and conduct quantitative and statistical data analysis to understand the interactions between drivers and pedestrian features at signalized intersections. The second objective was to produce tangible outcomes and detailed findings based on the detailed quantitative and statistical analysis. The third objective was to develop implementable countermeasures in engineering, education, and enforcement regarding pedestrian features at signalized intersections based on the tangible outcome and detailed findings produced.

### 1.4. Report Organization

This report is organized into eight chapters as follows:

1. Introduction
2. Establishment of Data Parameters for Data Request
3. IRB Approval, Data Sharing Agreement, and Data Acquisition
4. Enhancement of Data Extraction and Data Analysis Tools
5. Methodology for Quantitative and Statistical Analysis
6. Data Analysis and Findings
7. Development of Implementable Countermeasures
8. Conclusions and Recommendations

# 2. ESTABLISHMENT OF DATA PARAMETERS FOR DATA REQUEST

This project involves the NDS database, one of the largest databases of its kind. A secondary database, the Road Information Database (RID), provides information on the roads on which NDS participants traveled most frequently. As part of Task 1, the research team updated the existing RID with the updated information provided by CTRE on January 2016. The RID includes features such as signs, markings, lanes, Annual Average Daily Traffic (AADT), alignment, crashes, geometry, and other characteristics of the roadway on which the NDS participants drove. The research team also contacted VTTI to obtain information on the data extraction and pricing structure so that optimization of the data request with the current budget is achieved.

The pedestrian features on which the team focused are explained in detail in the following sections.

## 2.1. Selected Pedestrian Features

Features were selected based on interest from FDOT District 7 and the FDOT Research Center and because these features contribute to pedestrian safety and because of Florida's high ranking related to pedestrian crashes, fatalities, and injuries in the nation.

### *2.1.1. "STOP HERE ON RED" Sign*

According to the *Manual on Uniform Traffic Control Devices* (MUTCD), Section 8B.12, a "STOP HERE ON RED" sign (R10-6, R10-6a) defines and facilitates observance of stop lines at traffic control signals. As an option, a "STOP HERE ON RED" sign may be used at locations at which highway vehicles frequently violate the stop line or where it is not obvious to road users where to stop.


**Figure 1 - "STOP HERE ON RED" signs**

This feature is used primarily when the stop bar is not visible or drivers do not stop behind the stop bar at a signalized intersection. The research team identified locations in the area where this sign has been used to help in the compliance of drivers stopping behind the stop bar or not stopping on the crosswalk, therefore impeding crossing pedestrians. A total of 54 (46+8) of these signs exist in the RID database for the Florida region.

### *2.1.2. "NO TURN ON RED" Sign*

According to MUTCD, Section 2B.54, a "NO TURN ON RED" sign is used where a right turn on red (or a left turn on red from a one-way street to a one-way street) is to be prohibited; either a symbolic "NO TURN ON RED" (symbolic circular red) (R10-11) sign or a "NO TURN ON RED" (R10-11a, R10-11b) word message sign must be used. If used, the "NO TURN ON RED" sign should be installed near the appropriate signal head and should be considered when an engineering study finds that one or more of the following conditions exists:

- Inadequate sight distance to vehicles approaching from the left (or right, if applicable).
- Geometrics or operational characteristics of the intersection that might result in unexpected conflicts.
- An exclusive pedestrian phase.
- An unacceptable number of pedestrian conflicts with right-turn-on-red maneuvers, especially involving children, older pedestrians, or persons with disabilities.
- More than three right-turn-on-red accidents reported in a 12-month period for the particular approach.
- The skew angle of the intersecting roadways creates difficulty for drivers to see traffic approaching from their left.


**Figure 2 - "NO TURN ON RED" signs**

For the purposes of this study, the "NO TURN ON RED" sign is used when either an exclusive left-turn phase exists or drivers should not make a right turn conflicting with crossing pedestrians. A total of 52 (6+31+15) of these signs exist in the RID database for the Florida region.

### *2.1.3. "TURNING VEHICLES YIELD TO PEDESTRIANS" Sign*

According to MUTCD, Section 2B.53, a "TURNING VEHICLES YIELD TO PEDESTRIANS" sign is used to remind drivers making turns to yield to pedestrians at a signalized intersection.

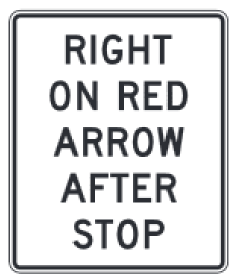

R10-15

**Figure 3 - "TURNING VEHICLES YIELD TO PEDESTRIANS" sign**

In this study, this sign is used to identify compliance from drivers making right turns (as well as left turns) since it has been used extensively in the Tampa Bay Area as a reminder to drivers. A total of 46 of these signs exist in the RID database for the Florida region.

### *2.1.4. "RIGHT ON RED ARROW AFTER STOP" Sign*

According to MUTCD, Section 2B.54, this sign is used in the same manner as the "No Turn on Red" sings.




R10-17a

**Figure 4 - "RIGHT ON RED ARROW AFTER STOP" sign**

For this study, this sign was observed in conjunction with a "PHOTO ENFORCED" plaque where red light cameras exist at intersections. Even though red light cameras enforce red light running, this sign assists with pedestrian crossings because it enforces no right on red or right on red after stop requirements. A total of seven of these signs exist in the RID database for the Florida region.

### *2.1.5. Permitted Left Turn*

Although this is not a pedestrian feature as such, permitting left turns is significant when drivers are not paying attention to pedestrians that are crossing the side street, thus creating a potential conflict.

## 2.2. Research Questions

In Phase 2, the research team built on Phase 1 to answer the study question in detail, “How do drivers interact with pedestrian features at signalized intersections when pedestrians are or are not present?” The pedestrian features for this research project include the following pedestrian safety-related signs and signals: (1) “STOP HERE ON RED,” (2) “NO TURN ON RED,” (3) “TURNING VEHICLES YIELD TO PEDESTRIANS,” (4) “RIGHT ON RED ARROW AFTER STOP” and “PHOTO ENFORCED,” and (5) “PERMITTED LEFT TURN SIGNALS.” Driver interactions with pedestrian features include driver speeds, braking patterns, yielding behaviors, and attention and/or distraction. Phase 1 successfully demonstrated the success of the proof-of-concept for the development of countermeasures. Phase 2 completes the research and develops effective and implementable countermeasures that can lead to significant improvement in pedestrian safety at signalized intersections.

Phase 2 research continues to align with the American Association of State Highway and Transportation Officials (AASHTO) Safety Task Force’s focus areas of (1) driver speed, (2) roadway features and driver performance, (3) preceding contributory events, (4) vulnerable road users, and (5) intersections.

Based on the success and lessons learned from Phase 1, the research team modified and enhanced the research plan, NDS data request, analysis methodologies, and research tools developed in Phase 1 to successfully complete Phase 2 on (1) interactions between drivers and pedestrian features at signalized intersections and (2) driver characteristics, behaviors, and performance with respect to studied pedestrian features. Based on the Phase 1 experience, the potential outcomes of the research in Phase 2 include the following:

1. Better understanding and detailed findings of the effectiveness of studied pedestrian features at signalized intersections with and without the presence of pedestrians.
2. Better understanding and detailed findings of driver behaviors and compliance with studied pedestrian features at signalized intersection with respect to age, gender, and driving attitudes.
3. Enhancement of research tools developed in Phase 1 to extract and analyze NDS data and recorded videos at signalized intersections to detect the presence of pedestrians, identify traffic signal indications, and organize NDS data for detailed analysis.
4. Development of implementable countermeasures based on the effectiveness of studied pedestrian features and the impact of driver characteristics and demographics on compliance with the intention of the pedestrian features.

## 2.3. Supporting Data Sets for Research

SHRP2 NDS data consist of two large datasets. The main dataset includes naturalistic driving data from instrumented vehicles and supplemental driver information managed by VTTI; the second dataset includes an RID managed by the Center for Transportation Research and Education (CTRE).

The data needed to conduct the Phase 2 project came from the same datasets as in Phase 1. The major difference is the amount of data needed for a large sample for statistical analysis on the effectiveness of pedestrian features and comprehensive analysis on the impact of driver characteristics and behaviors on compliance with pedestrian features. A large sample size with pedestrian presence also was needed. This was an issue with Phase 1 data—pedestrian presence was found in only 7.5% of the requested short videos. In addition, not all pedestrian presence warrants attention from a driver; only pedestrians close to a crosswalk or actively crossing are of concern. This area was a larger focus in Phase 2 so a detailed analysis could be performed and comprehensive results obtained. In addition to increased pedestrian presence, a larger number of videos provided a larger sample of drivers arriving at an intersection when the signal is red instead of green, since the studied features apply primarily to red signal indication.

Because the traffic signal indication is not available in the NDS dataset, videos of red-signal-only activity could not be requested. With the use of the video detection tool developed in Phase 1 by the research team, more videos can be scanned to flag the change of signal, thereby providing a sample that will show red signal indications when drivers arrive at an intersection. The research team may acquire data as needed from one of five sites to supplement Tampa Bay site data.

During Phase 1, 2,700 videos were requested and provided by VTTI, but 16% were not usable for several reasons: the video was obstructed by an object on the vehicle's windshield, the video resolution was so low that features could not be determined, the video was blurred (out of focus), there was no video (file was blank), and the video segment provided started in the wrong place since the main interest was when a driver was passing through an intersection. With a larger sample size and adequate funding, the researchers can scrap these videos and request more to account for this occurrence. This could not be accomplished in Phase 1 due to limited funds and time.

In Phase 2, the number of video segments for each feature site was doubled by either adding more intersections or requesting more traversals per intersection. This ensured adequate data for analysis. Also, the number of full trips was doubled to allow for more information per participant to observe driving behaviors at multiple intersections. This number also accounted for the unusable videos and videos of green time through an intersection (red time is preferred).

Personally Identifiable Information (PII) data will not be used in Phase 2.

### 2.4. Data Parameters

The research team identified that more data were needed for Phase 2 to achieve significant results of the analysis. For this phase, a need was identified for an estimated 162 signalized intersections that include the selected features, with an additional 12 intersections serving as control sites. (Based on the effort and cost to extract the necessary data, this number was reduced.) Drivers were divided into nine age groups, as in Phase 1. Overall, 10% of driver trips were full trips rather than a 30-second segment passing at the intersection, and 5% were during nighttime (9:00 PM–5:00 AM). Based on the NDS database structure, the following parameters were selected to be included in the data.

#### *2.4.1. Trip Summary Measures*

The trip summary dataset is a collection of variables that summarize the characteristics of continuous data files collected during the SHRP 2 NDS. Variables are organized into a table in which each row represents a summary record describing the content of an individual trip. The trip summary records are generated after a trip has been ingested into the SHRP 2 NDS database and has passed quality assurance processes. This dataset is intended to provide information about the types of trips that exist in the continuous time series database (e.g., trip duration, day of week, time of day, maximum speed, etc.). These measures are for the trips in which the selected intersections are traversed. The variables are:

- Brake Activations
- % CTRE Van Cov
- % HSIS Derived Rd Class
- % Other Class
- % Rur 2 Ln
- % Rur Frwy
- % Rur Frwy < 4 Lns
- % Rur Multi Div Non-Frwy
- % Rur Multi Undiv Non-Frwy
- % State Data Cov
- % Urb 2 Ln
- % Urb Frwy
- % Urb Frwy < 4 Lns
- % Urb Multi Div Non-Frwy
- % Urb Multi Undiv Non-Frwy
- % No Spd Lim Data
- % Spd Lim 35 or Less
- % Spd Lim 40-50
- % Spd Lim 55-65
- % Spd Lim 70 or Greater
- Trip Start Local Time Hour of Day
- Trip End Local Time Hour of Day
- ABS Available
- ABS Activation
- Mean Speed

- Max Speed
- Turn Signal Available
- Turn Signal Activations
- Cell Phone Flag

### *2.4.2. Event Data*

Identified events were near-crashes that occurred at the selected intersections (crashes not provided because of potential participant identification). The variables are:

- Event Nature 1
- Event Nature 2
- Relation To Junction
- Incident Type 1
- Incident Type 2
- Intersection Influence
- Final Narrative
- Driver Behavior 1
- Driver Behavior 2
- Driver Behavior 3
- Secondary Task 1
- Secondary Task 1 Start Time
- Secondary Task 1 End Time
- Secondary Task 1 Outcome
- Secondary Task 2
- Secondary Task 2 Start Time
- Secondary Task 2 End Time
- Secondary Task 2 Outcome
- Secondary Task 3
- Secondary Task 3 Start Time
- Secondary Task 3 End Time
- Secondary Task 3 Outcome

### *2.4.3. Driver Data*

Data were provided for the participants represented in the sample. Note that some assessment data, or combinations of assessment data, were considered potentially PII and could not be provided outside VTTI’s secure data enclave. The variables are:

- Driver Demographic Questionnaire (all available answers)
- Driver History Questionnaire (all available answers)
- Driving Knowledge Survey (all available answers)
- Barkley’s ADHD Screening Test (all available answers)
- Behavior Questionnaire (all available answers)

- Risk Taking Questionnaire (all available answers)
- Risk Perception Questionnaire (all available answers)
- Medical Conditions & Medications (all available answers)

#### *2.4.4. Vehicle Data*

The vehicles dataset is a collection of variables that describe each vehicle that was instrumented for data collection in the SHRP 2 NDS study. Each row of the dataset provides descriptive information about the type and condition of the vehicle. Information about integrated technologies on the vehicle is also included. Individual vehicle records may be linked to multiple participants if more than one member of a household participated in the program. These data were provided for the vehicles represented in the sample. The variables are:

- Make
- Model
- Year

#### *2.4.5. Time Series Data*

Time series data are variables collected from vehicles by the SHRP 2 NDS on-board data acquisition system. The data are collected continuously while the vehicle is running from the vehicle data network and a variety of sensors. These data were provided for the trip segments in the sample. A trip segment is defined as the time the participant is on the link IDs which define an intersection. The variables were selected from the following list, when available, for the events of interest:

- vtti.speed_network
- vtti.speed_gps
- vtti.accel_x
- vtti.accel_y
- vtti.accel_z
- vtti.pedal_gas_position
- vtti.head_confidence
- vtti.pedal_brake_state
- vtti.abs
- vtti.turn_signal
- steering wheel position
- wiper setting
- GPS heading
- Timestamp
- subjectID
- video, forward roadway
- latitude and longitude

### *2.4.6. Video*

Videos of the forward roadway were provided for the events of interest in separate MP4-format files linked by name to the time series data file.

### *2.4.7. Selected Intersections*

Based on the features identified and the trip density maps provided by VTTI (see Figure 5), the research team selected intersections for which to request NDS data, as shown in Tables 1, 2 and 3. Each feature is included in several intersections, and one or two control sites with similar AADT, trip density, and geometry (lanes, crosswalks etc.) will be used for the baseline analysis.

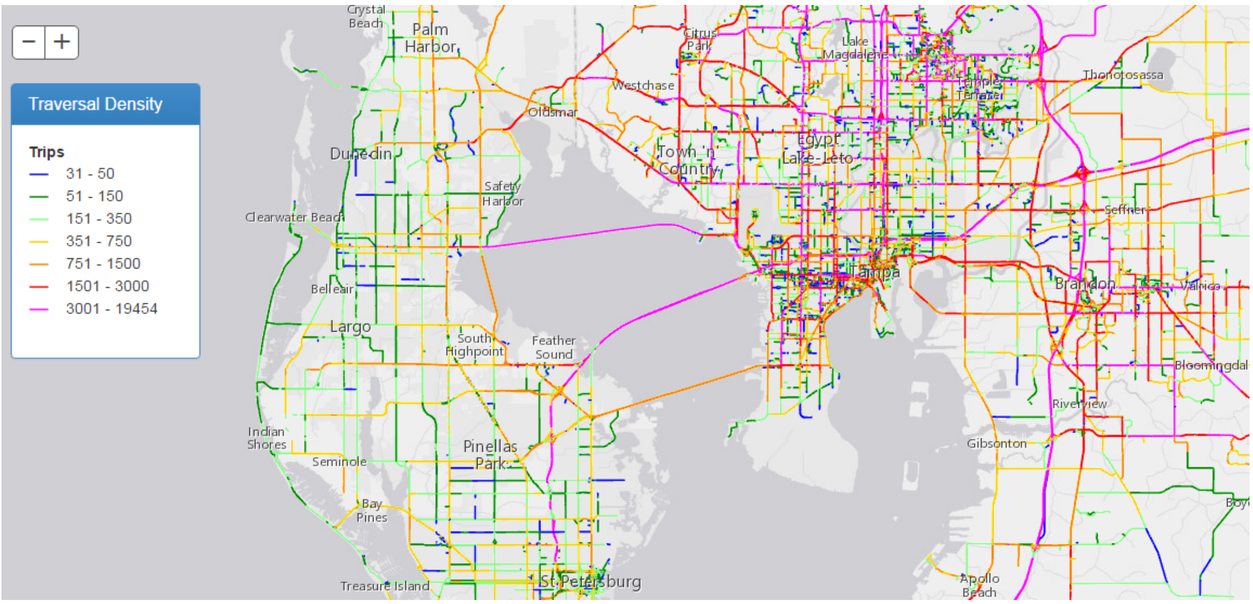



**Figure 5 - Traversal density map for Tampa Bay Area, Florida**

## 2.5. Data Request

The data were obtained from the custodian of the SHRP2 NDS data, VTTI. Similar to Phase 1, a data sharing agreement and contract with USF and VTTI was agreed upon and signed so that work on the data extraction and acquisition could occur. With the generous support of FDOT, a larger budget for data allowed the research team to request up to 40,000 trip segments from 157 intersections so that statistically significant analysis was achieved. The data request process included several steps:

1. VTTI provided summary of available data based on intersections and approaches of interest.
2. Agreement on scope of work for VTTI with data parameters outlined.
3. Agreement and finalization of budget with exact data to be acquired.
4. Execution of contract and data sharing agreement.

After these steps, VTTI provided the data to the research team for analysis in several batches.

# 3. IRB APPROVAL, DATA SHARING AGREEMENT, AND DATA ACQUISITION

## 3.1. IRB Approval

This research project involved data collected from human subjects and, therefore, was subject to Institutional Review Board (IRB) approval of the research protocol, methods, and data collection.

An application was submitted to the University of South Florida (USF) IRB, the body that oversees behavioral research at the University. The application was submitted on March 16, 2016; the submitted protocol can be found in Appendix A. The determination of the IRB based on the type of data to be used was that the study is exempt from IRB review. The letter can be found in Appendix B.

## 3.2. Data Sharing Agreement

To work with the Virginia Transportation Institute (VTTI) and acquire data from the Strategic Highway Research Program 2 (SHRP2) Naturalistic Driving Study (NDS) dataset, a Data Sharing Agreement and contract with VTTI was established. The CUTR research team worked with VTTI staff to submit the official data request, which included the data sharing agreement and the scope of work for VTTI to extract the requested data.

## 3.3. Data Acquisition

The process to acquire the data started with the data sharing agreement and contract with VTTI. The CUTR research team was assigned a VTTI data analyst to work with the data. The process started in October 2016; the Data Sharing Agreement was signed on October 6, 2016 and the contract was signed on November 18, 2016. The analyst started working on data extraction in December 2016 and provided the first batch of data on February 22, 2017; the last data batch was provided on March 6, 2017.

The request for data was further divided into age and gender by feature so a more even data representation was achieved. Table 2 shows the requested trips.

**Table 2 - Data Request by Age/Gender/Feature**

| Feature | Male 16-24 | Male 25-44 | Male 45-64 | Male 65+ | Female 16-24 | Female 25-44 | Female 45-64 | Female 65+ | Total |
|---|---|---|---|---|---|---|---|---|---|
| NO TURN ON RED | 2,000 | 565 | 838 | 979 | 1,596 | 2,000 | 1,003 | 593 | **9,574** |
| RIGHT ON RED ARROW AFTER STOP | 1,633 | 343 | 590 | 382 | 1,200 | 864 | 251 | 284 | **5,547** |
| STOP HERE ON RED | 1,500 | 1700 | 1,700 | 2,000 | 1,700 | 1,700 | 1,700 | 2,500 | **14,500** |
| TURNING VEHICLES YIELD TO PEDS | 1,602 | 1,151 | 821 | 1,386 | 2,000 | 1,707 | 957 | 755 | **10,379** |
| **Total** | **6,735** | **3,759** | **3,949** | **4,747** | **6,496** | **6,271** | **3,911** | **4,132** | **40,000** |

The actual data received varies slightly per feature (if there were not enough data). The data summary is shown in Table 3.

**Table 3 - Data Summary**

| Data | Amount Received | Amount Valid* | Amount Used |
|---|---|---|---|
| Intersections (sites) | 110 | 99 | 99 |
| Videos | 30,002 | 28,338 | 8,569 |
| Trips | 40,002 | 28,338 | 8,569 |

** Some trips did not have videos due to proximity of start or end of trip. These videos were omitted for privacy of participants. Some videos were of poor quality or were blank files.*

# 4. ENHANCEMENT OF DATA EXTRACTION AND DATA ANALYSIS TOOLS

Two data extraction and analysis tools were developed in Phase 1 to produce the dataset for analysis from the NDS datasets obtained from VTTI and CTRE. In Phase 2, the two computer tools were enhanced based on the experience from Phase 1 to improve data reduction efficiency and accuracy. The following sections provide the description used to enhance the tools.

## 4.1. Improvement of NDS Data Reduction and Analysis Tool (DRAT)

The NDS Data Reduction and Analysis Tool (DRAT) is a computerware application on the platform of Microsoft .NET framework 4.0. Researchers can use this tool to review NDS front videos and associated speed data. By clicking pre-defined event buttons, the event data can be recorded and exported to the project database automatically. The data conversion function (from raw data to final data) is also integrated into this tool.

The major functions of the NDS DRAT include:

- Displaying NDS front videos and associated speed profile synchronously
- Recording pre-defined events and associated timeline automatically when reviewers click event buttons
- Exporting extracted data (raw data) to a project database (hosted in a MS SQL Server)
- Converting raw data to final data according to the needs of analysis
- Allowing users edit extracted data
- Generating data reports for second reviewing
- Providing user and data management

In Phase 2, the DRAT tool was upgraded to satisfy the needs of new data reduction procedure. The major updates include:

- Fine-tune the user interface to allow reviewers fast inputs
- Add Google-map links for validate site and pedestrian features

Figures 6, 7, 8 and 9 show user interfaces of DRAT tool for video management, speed profile, event input panel, and output reporting, respectively.

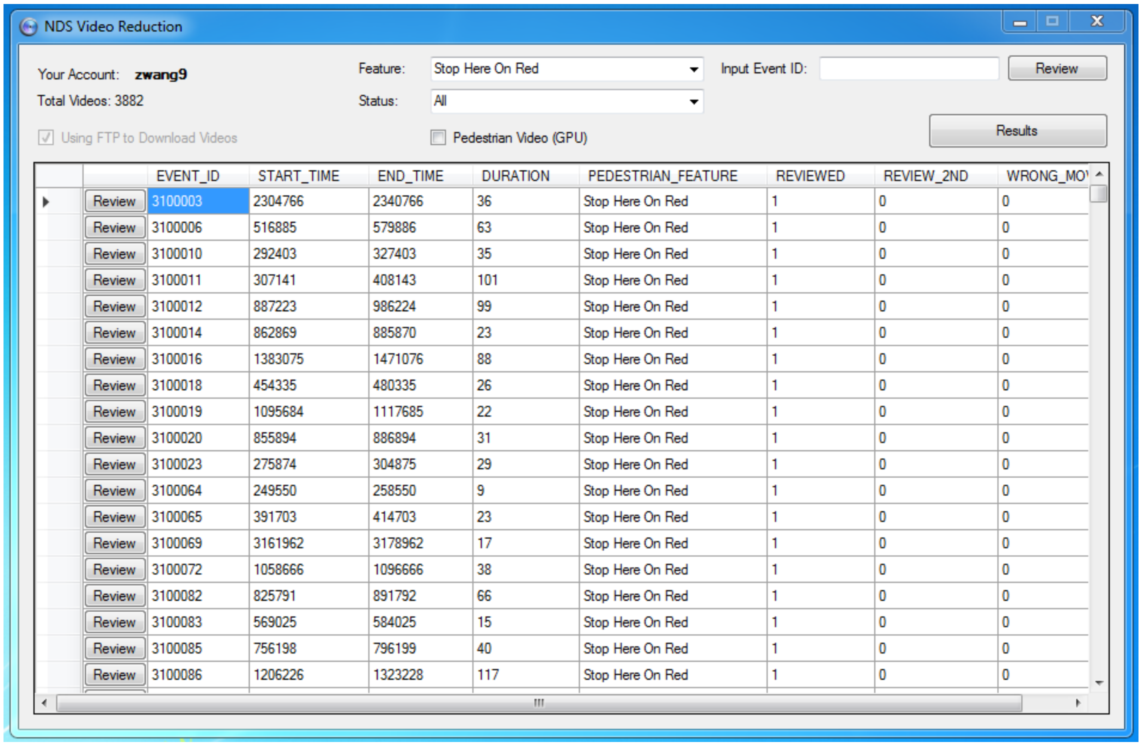



**Figure 6 - Video management interface of DRAT**

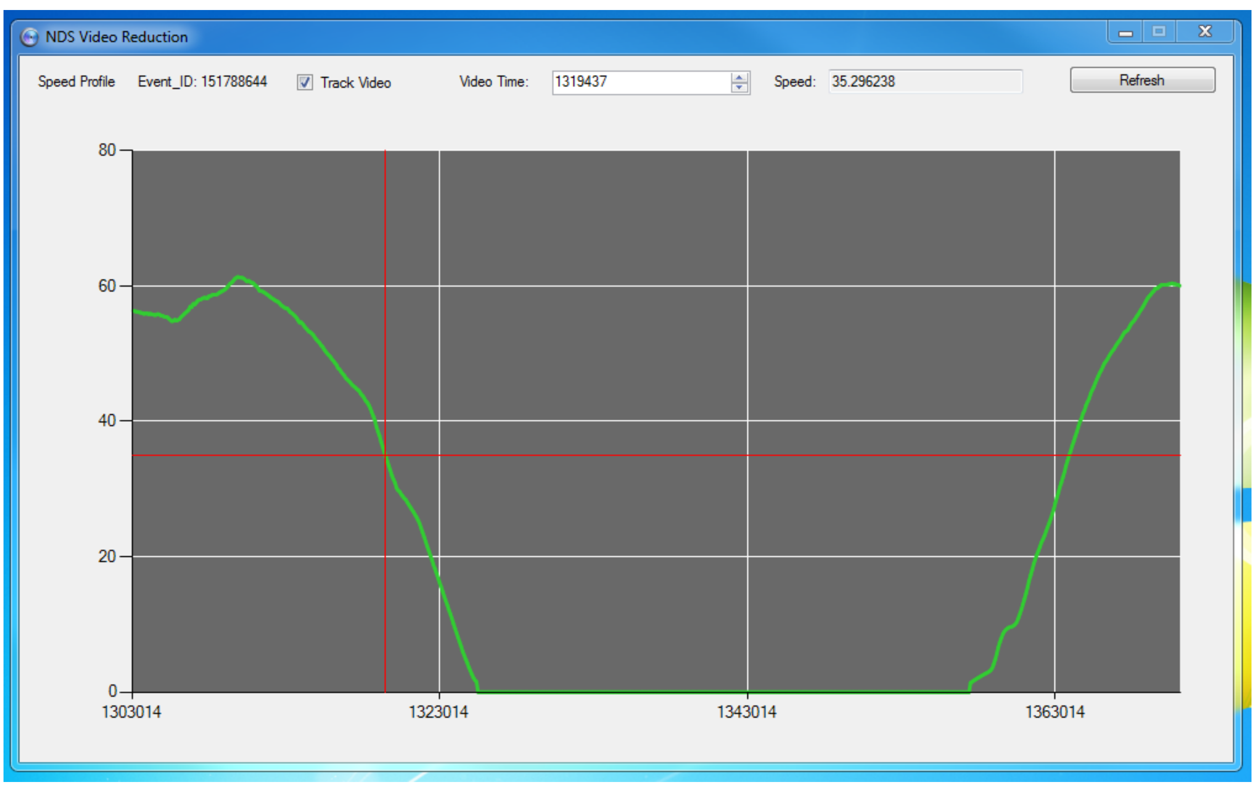



**Figure 7 - Speed profile interface of NDS Data Reduction and Analysis Tool**

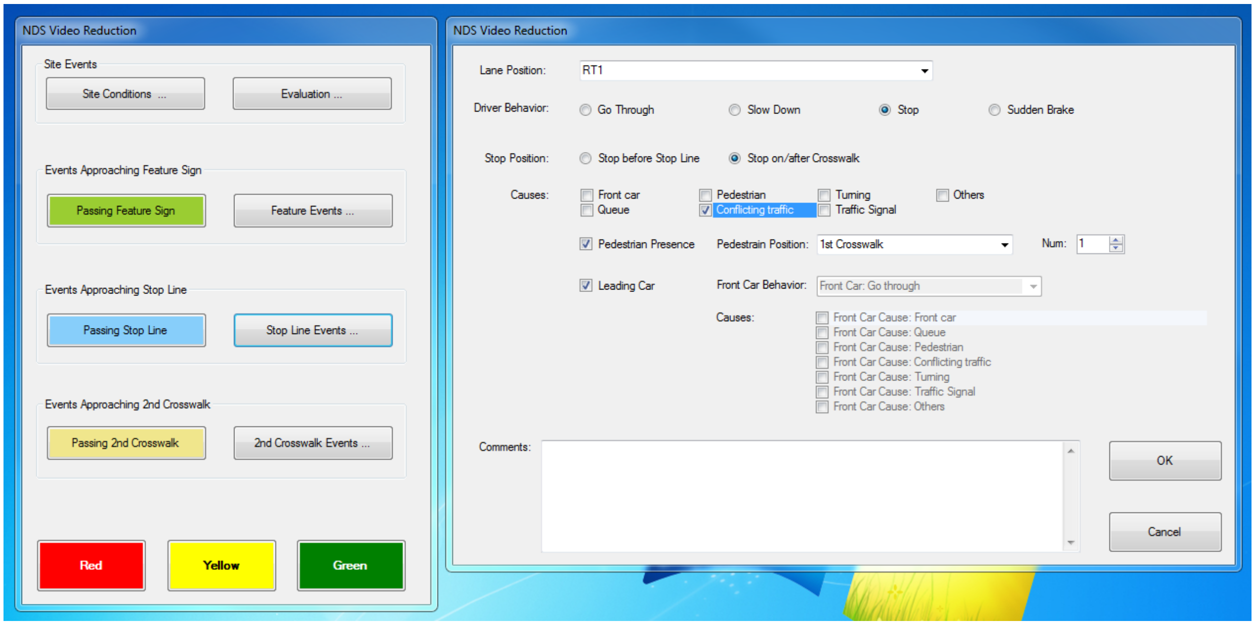
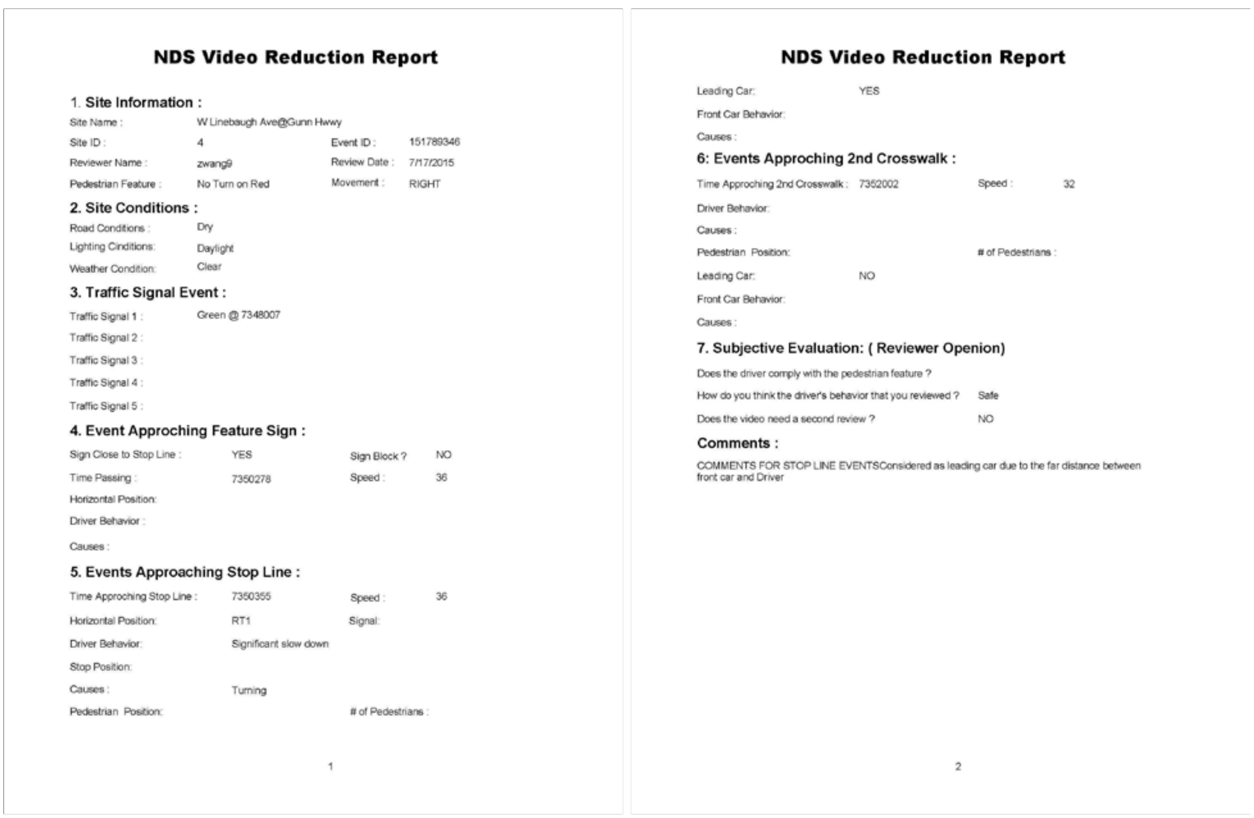



**Figure 8 - Pre-defined event panel of NDS Data Reduction and Analysis Tool**



**NDS Video Reduction Report**

1. Site Information :

| | | | |
|---|---|---|---|
| Site Name : | W Linebaugh Ave@Gunn Hwwy | | |
| Site ID : | 4 | Event ID : | 151789346 |
| Reviewer Name : | zwang9 | Review Date : | 7/17/2015 |
| Pedestrian Feature : | No Turn on Red | Movement : | RIGHT |

2. Site Conditions :

Road Conditions : Dry
Lighting Cinditions: Daylight
Weather Condition: Clear

3. Traffic Signal Event :

Traffic Signal 1 : Green @ 7348007
Traffic Signal 2 :
Traffic Signal 3 :
Traffic Signal 4 :
Traffic Signal 5 :

4. Event Approching Feature Sign :

Sign Close to Stop Line : YES Sign Block ? NO
Time Passing : 7350278 Speed : 36
Horizontal Position:
Driver Behavior :
Causes :

5. Events Approaching Stop Line :

Time Approching Stop Line : 7350355 Speed : 36
Horizontal Position: RT1 Signal:
Driver Behavior: Significant slow down
Stop Position:
Causes : Turning
Pedestrian Position: # of Pedestrians :

1

**NDS Video Reduction Report**

Leading Car: YES
Front Car Behavior:
Causes :

6: Events Approching 2nd Crosswalk :

Time Approching 2nd Crosswalk : 7352002 Speed : 32
Driver Behavior:
Causes :
Pedestrian Position: # of Pedestrians :
Leading Car: NO
Front Car Behavior:
Causes :

7. Subjective Evaluation: ( Reviewer Openion)

Does the driver comply with the pedestrian feature ?
How do you think the driver's behavior that you reviewed ? Safe
Does the video need a second review ? NO

Comments :

COMMENTS FOR STOP LINE EVENTSConsidered as leading car due to the far distance between front car and Driver

2

**Figure 9 - Example of NDS Data Reduction and Analysis report**

## 4.2. Enhancement of NDS Automatic Video Processing Tool (AVPT)

The scenarios of pedestrian presence are the major research interests in this project. It is impossible to review all 40,000 videos to select pedestrian scenarios. To improve the effectiveness of video data extraction to support analysis, the research team developed the NDS Automatic Video Processing Tool (AVPT) to detect pedestrian from NDS videos using computer image processing technologies in Phase 1. However, the first version of AVPT has several limitations to prevent its application on Phase 2 data:

- The first version was coded on the MATLAB platform. Its detection speed is too low to process a large-scale dataset.
- The performance to process low-quality videos is poor. Due to the capacity limitation, the low-quality videos account for a great portion of NDS data.

In Phase 2, several improvements were implemented to make the AVPT more robust, efficient, and accurate for actual use, including the following:

- Applied deblurring filters to aid in video sharpness and increase detection accuracy for low-resolution videos as shown in Figure 10.
- Compared algorithms and functions to optimize possible configurations and outputs.
- Coded algorithms on OpenCV + CUDA platform by C++ to use GPU capability for dramatically increasing processing speed.

**Figure 10 - Pedestrian detection without deblurring filter (*left*) and with deblurring filter (*right*)**

These improvements greatly enhanced the performance of AVPT tool. As shown in Figure 11, the new APTV tool can increase the average detection rate on low-resolution videos to 90%. The improvement rate is 64% (= [90% − 55%] ÷ 55% × 100%) from the old version. The detection time with the new APTV tool is also decreased to 1.06 seconds per one video second. The improvement rate is 97% (= [40s − 1.06s] ÷ 40s × 100%) faster than the old version.

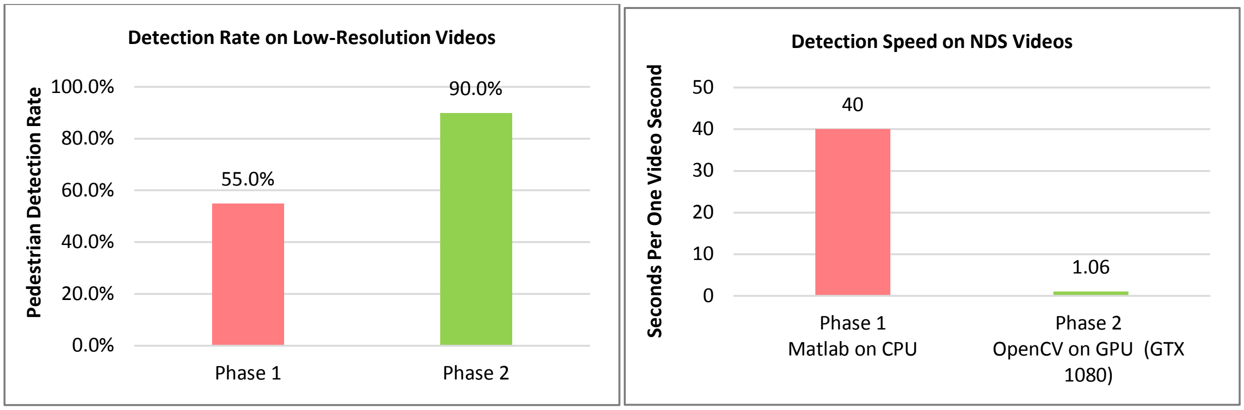



**Figure 11 - Comparison of detection performance of AVPT between Phase 1 and Phase 2**

The outputs provided by the data extraction and analysis tools, along with given driver characteristics from the NDS database and roadway characteristics from the RID, were used for qualitative, quantitative, and statistical analysis.

### 4.3. Data Reduction Results

The research team used the two tools to collect useful information from the original NDS videos, sensor data, and supplemental data. To reduce video reviewing time, the videos for "NO TURN ON RED," "STOP HERE ON RED," and "RIGHT ON RED ARROW AFTER STOP" signs were filtered by speed thresholds (only videos with low speed were selected for reviewing). For "TURNING VEHICLES YIELD TO PEDESTRIANS" signs, only videos with pedestrian presence were reviewed. In Phase 2, the research team reviewed 8,569 events (videos) at 99 sites as shown in Table 4.

**Table 4 - Summary of Reviewed Events and Sites in Phase 2**

| Pedestrian Feature (Sign) | Number of Events | Number of Sites |
|---|---|---|
| NO TURN ON RED | 2,260 | 29 |
| STOP HERE ON RED | 4,049 | 28 |
| YIELD TO PEDESTRIANS | 976 | 35 |
| RIGHT ON RED ARROW AFTER STOP | 1,284 | 7 |
| **Total** | **8,569** | **99** |

# 5. METHODOLOGY FOR QUANTITATIVE AND STATISTICAL ANALYSIS

## 5.1. Data used for Data Analysis

The research team identified 6 categories and 23 events for extraction from the NDS and RID datasets for different pedestrian features and organized for these datasets for specific data analysis. Since the size of the Phase 2 dataset is more than 14 times that of Phase 1, the research team focused on the most important data items identified in Phase 1, as shown in Table 5, to improve data reduction efficiency.

**Table 5 - Identified Events for Data Extraction and Analysis**

| Category | Event | Data Source |
|---|---|---|
| Site Conditions | Weather condition (clear, rain, …) | NDS Front Video, Google Map |
| | Lighting condition (daylight, dark, …) | |
| | Pedestrian feature location | |
| Driver Behaviors | Traffic signal when arriving at stop bar | NDS Front Video |
| | Timeline arrive at stop bar | |
| | Lane choice | |
| | Driving behavior when approaching stop bar | |
| | Stop position (before or passing stop bar) | |
| | Contributing factors to driving behaviors | |
| Pedestrian | Yield to pedestrians or not | NDS Front Video |
| | Pedestrian location (sidewalk, crosswalk, …) | |
| Driver Characteristics | Age group | NDS Supplementary Data |
| | Gender | |
| | Risk level | |
| | Distraction level | |

## 5.2. Data Reduction and Management

To process the large scale of dataset in Phase 2, the research team adopted the procedure of data extraction and analysis procedure shown in Figure 12. To reduce the quantities of videos for human review, which are the most time-consuming task, video review focused on two kinds of videos:

– Videos detected as “pedestrian presence” by AVPT

– Videos that the lowest speed is lower than a threshold (5 mph) because the signal status on these videos are most likely to be “red” when approaching stop bar.

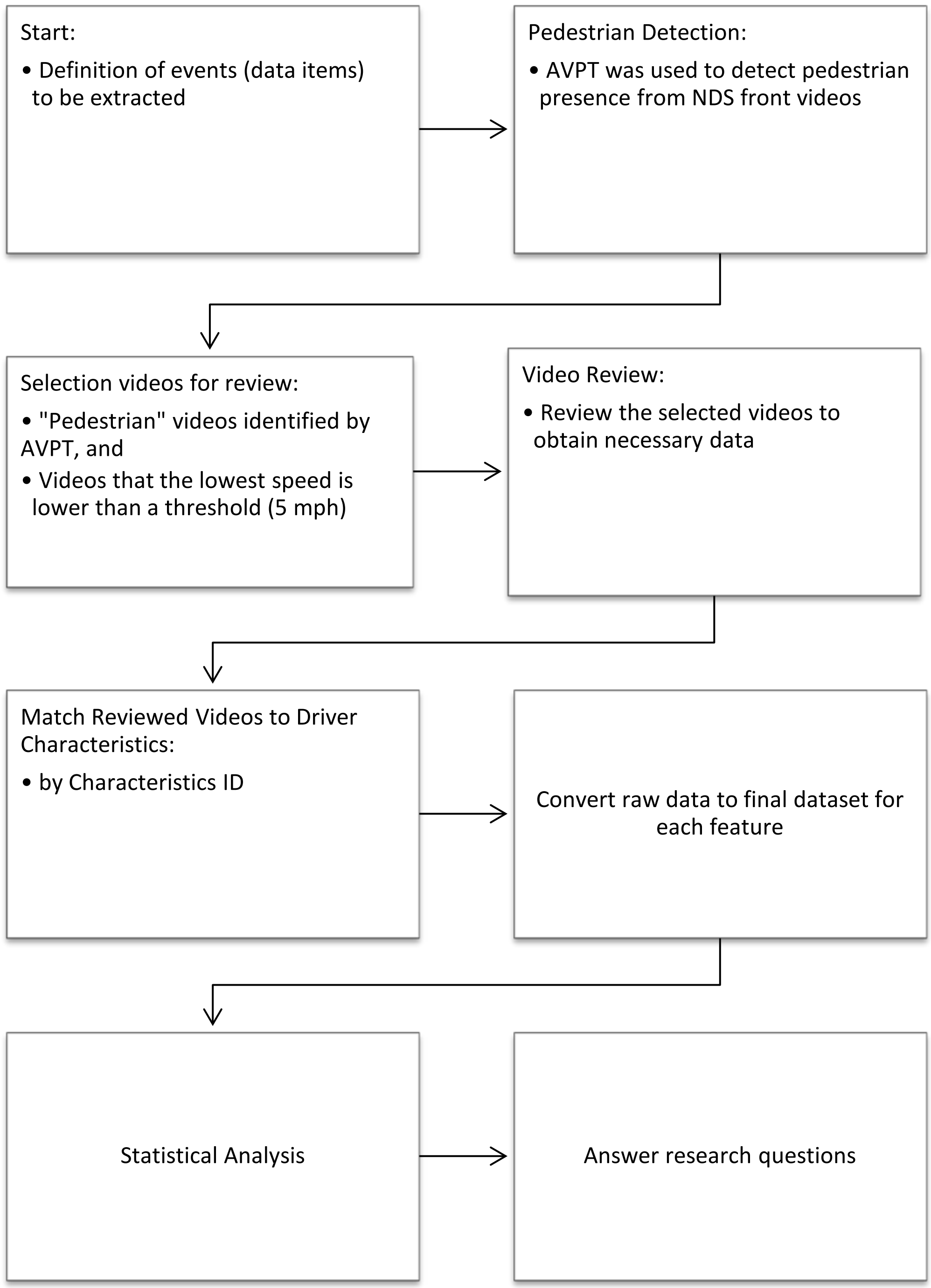



**Figure 12 - Data processing and analysis procedure**

## 5.3. Quantitative and Statistical Analysis

The cross-sectional analysis was used in this study to assess the safety effectiveness of the selected pedestrian feature. In this analysis, the observed compliant driver behaviors were categorized into two groups: feature group (with the pedestrian feature) and control group (without the pedestrian feature). A series of comparisons of the compliant behaviors was conducted between each feature group and its control group. The higher the proportion of compliant behaviors observed, the better the safety performance is. Chi-Square tests were used to determine whether the proportion of compliant driver behaviors at feature sites ($P_{FE}$) was significantly different from that at control sites ($P_{CE}$).

$H_0$: $P_{FE} = P_{CE}$ (proportion of compliant driver behaviors at feature sites is the same as that at control sites)

$H_a$: $P_{FE} \neq P_{CE}$ (proportion of compliant driver behaviors at feature sites is different from that at control sites)

The proportion comparisons also were conducted between different driver characteristics (gender, age, and risk groups) for each pedestrian feature. In addition, the difference in compliant behaviors by different driver characteristics and pedestrian presence was compared based on the overall data. All hypothesis tests were conducted at a minimum confident level of 90%.

### 5.4. Generalized Linear Mixed Model Analysis

The data quantitative and statistical analysis method was able to reveal driver compliant behavior distribution across different values of a certain variable and highlight the factor that deserves special attention. However, it may not accurately capture the distinctive impacts of these factors since these distributions were also affected by other unobserved factors to some extent. Therefore, a generalized linear mixed model (GLMM) is used in this study to examine the individual effect of traffic environment and driver demographic and behavioral variables on driver compliant behavior distribution. The response of interest in our study is driver compliant behavior at intersections with pedestrian features and is collected as binary data. Given a dataset including *n* observations, let $Y_i$ be the compliant behavior of the *i*th observation, where $Y_i = 1$ indicates that a driver complies with the pedestrian feature and $Y_i = 0$ otherwise, and the relationship between driver compliant behavior and the predictor variables is expressed as follows,

$$\log\left(\frac{P}{1-P}\right) = \log\left(\frac{P(Y=1)}{1-P(Y=1)}\right) = X\beta + Z^*T^* + \varepsilon, i = 1, \dots, n \quad (1)$$

Where, $P$ is the probability of driver compliant behavior at pedestrian features and $P_i = P(Y_i = 1)$ is the probability of compliance to the pedestrian feature for the *i*th observation. $X$ is an *n*-by-*p* matrix of *p* explanatory variables. $\beta$ is a *p*-by-1 column vector of regression coefficients for the *p* explanatory variables and represents the fixed effects in the model; $Z_i^*T^*$ is the component that represents random effects, where $Z_i^*$ is an *n*-by-*q* random-effects design matrix; $T^*$ is *q*-by-*1* vector of random effects. $\varepsilon$ is an *n*-by-*1* column vector of the error term that are not explained by $X\beta + Z^*T^*$. The modeling process is conducted in R and maximum likelihood estimation with Laplace Approximation method is used.

# 6. DATA ANALYSIS AND FINDINGS

This chapter documents the data analysis process and research findings based on the comprehensive NDS data obtained from VTTI in the Phase 2 research project. Data analyses were conducted and research findings were summarized for data of each individual pedestrian features and the overall dataset. As stated, significant analyses were conducted at 95% confidence level, with a 90% confidence level as additional evidence. A comprehensive and in-depth understanding of the interactions between drivers and pedestrian features is important for developing effective countermeasures to improve pedestrian safety at signalized intersection. Therefore, the research findings in Phase 2 were also compared with existing literature regarding the selected pedestrian features in Section 6.2.

## 6.1. Individual and Overall Analysis

The data analysis in Phase 2 answered the major Phase 2 research question, "Based on information from the SHRP2 NDS and RID datasets, how do drivers interact with pedestrian features at signalized intersections?" Quantitative and statistical analyses were conducted for each of the four pedestrian features individually and overall. For each feature, the following data analyses were performed:

– Interactions between drivers and pedestrian features
– Comparison of compliant behaviors with features between feature and control sites
– Comparison of compliant behaviors with features between daytime and nighttime
– Comparison of compliant behaviors at feature sites by driver gender, age group, education level, and attention-deficit/hyperactivity disorder (ADHD) level
– Comparison of compliant behavior at feature sites by feature sign locations
– Driver behavior consistency analysis in multiple trips with a same feature

In addition, overall comparisons (including all features) were conducted to explore:

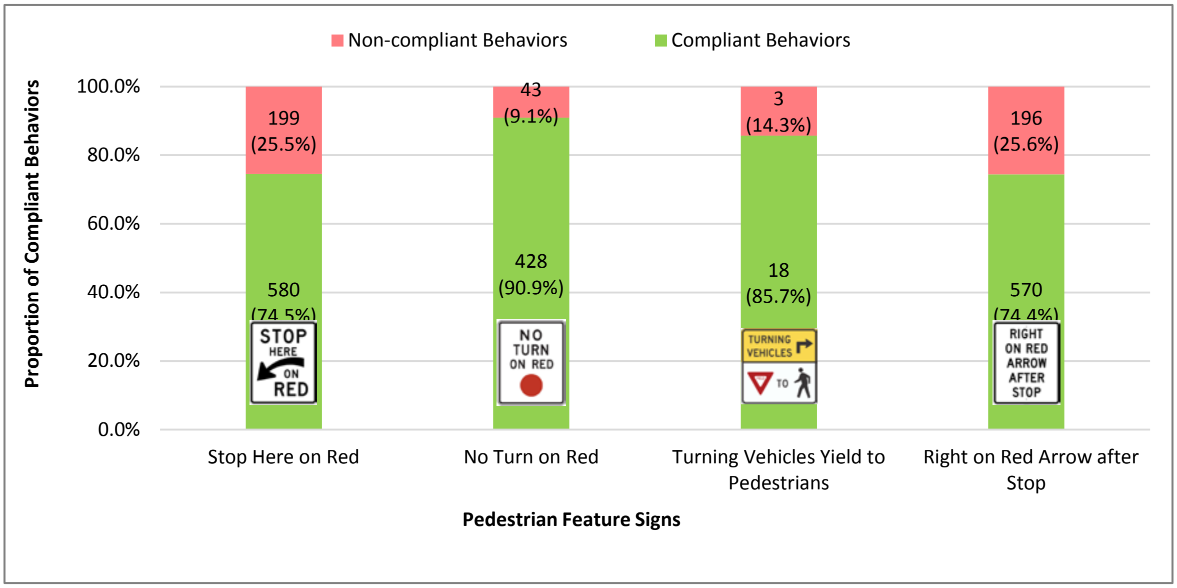
– Driver behavior consistency analysis by gender and age group information.
– Impact of pedestrian presence on driver-feature interactions
– Impact of driver characteristics (behavioral characteristics, risk, distraction) on compliant behaviors

The analysis results and research findings are presented below. It should be noted that Observations of stopping behaviors affected by leading traffic were removed from the analysis. The column label on the graphs shows the sample size and percentage for each feature shown.

### *6.1.1. Individual Analysis: Interactions between Drivers and Pedestrian Features*

Figure 13 shows the distribution of interactions between drivers and feature signs for each pedestrian feature. Overall, drivers demonstrated the highest proportion of compliant behavior at "NO TURN ON RED" sign (90.9%), followed by those for "TURNING VEHICLES YIELD TO

PEDESTRIANS" (85.7%), "STOP HERE ON RED" (74.5%) and "RIGHT ON RED ARROW AFTER STOP" (74.4%). A description of results for each feature is provided as follows.




| Pedestrian Feature Signs | Non-Compliant Counts | Compliant Counts | Total Counts | % Non-Compliant Behaviors | % Compliant Behaviors |
|---|---|---|---|---|---|
| STOP HERE ON RED | 199 | 580 | 779 | 25.5% | 74.5% |
| NO TURN ON RED | 43 | 428 | 471 | 9.1% | 90.9% |
| TURNING VEHICLES YIELD TO PEDESTRIANS | 3 | 18 | 21 | 14.3% | 85.7% |
| RIGHT ON RED ARROW AFTER STOP | 196 | 570 | 766 | 25.6% | 74.4% |

**Figure 13 - Interactions between drivers and studied pedestrian features**

"STOP HERE ON RED" Sign:

– Drivers stopped on red in 95.3% of all observations, including stopping before the stop line in 74.5% of observations (compliant behavior), and stopping past the stop line in 20.8% of observations. Drivers did not stop on red in 4.7% of observations. (Note: Most non-stopping observations were right turns where drivers yielded and turned on red when the roadway was clear.)

– In total, 10 observations were made with a pedestrian presence at the intersection with a "STOP HERE ON RED" sign. Seven observations fully complied by stopping before stop line, and three observations stopped past the stop line.

"NO TURN ON RED" Sign:

- Drivers stopped until the green signal came on (compliant behavior) in 90.9% of all observations, which is the highest proportion of driver compliance among all the feature signs. Drivers turned on red (non-compliant behavior) in 9.1% of observations, including 2.8% who did not stop at the red signal light and 6.3% who stopped and turned.
- Four observations were made with pedestrian presence at intersections with a “NO TURN ON RED” sign. Three fully complied (stopped before stop line and waited for green light), and one did not comply with the “NO TURN ON RED” sign.

“TURNING VEHICLES YIELD TO PEDESTRIANS” Sign:

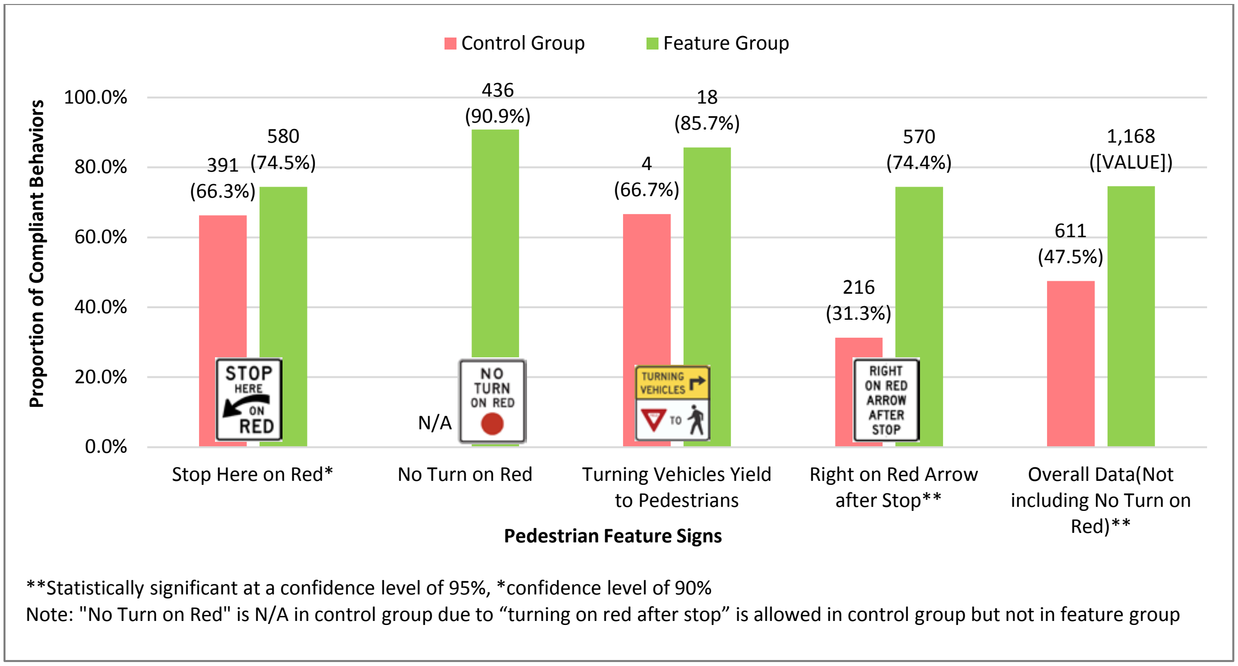
- Drivers yielded to pedestrians in 85.7% of all observations (compliant behavior); in 14.3% of observations, drivers did not yield (non-compliant behavior).
- In 9 observations, drivers complied by stopping and yielding to pedestrians, and in another 9 observations, drivers complied by slowing down and yielding to pedestrians.
- Limited pedestrian presence was observed for this feature. Many observations with pedestrian presence were excluded in the analysis shown in Figure 3 since there was no interaction between drivers and pedestrians (e.g., pedestrians waited at the roadside for a “Walk” signal, pedestrians were walking away from the study vehicle, etc.).

“RIGHT ON RED ARROW AFTER STOP” Sign:

- Drivers complied in 74.4% of all observations and did not comply in 25.6% observations.
- Eight observations were made with a pedestrian presence at the intersection with “RIGHT ON RED ARROW AFTER STOP” signs. In all of these observations, drivers complied with the sign.

#### *6.1.2. Individual Analysis: Comparison between Feature Group and Control Group*

Figure 14 shows the results of comparison of driver compliant behaviors with features between each feature group and its associated control group. The control group data were from two sources based on site feature information. First, intersections without any of the four pedestrian features as control sites and data from these intersections were taken as control data. In addition, some data from sites with one feature could be used as control data for another feature. For example, data from “TURNING VEHICLE YIELD TO PEDESTRIANS” feature under right light condition could be used as control data for “NO TURN ON RED” “STOP HERE ON RED” and “RIGHT ON RED ARROW AFTER STOP” features, these data were also selected as the control data for the three features in the analysis.




| Pedestrian Feature Signs | Comparison Group | Non-Compliant Counts | Compliant Counts | Total Counts | % Compliant Behaviors |
|---|---|---|---|---|---|
| STOP HERE ON RED | Control Group | 199 | 391 | 590 | 66.3% |
| | Feature Group | 199 | 580 | 779 | 74.5% |
| NO TURN ON RED | Control Group | N/A | | | N/A |
| | Feature Group | 43 | 428 | 471 | 90.9% |
| TURNING VEHICLES YIELD TO PEDESTRIANS | Control Group | 2 | 4 | 6 | 66.7% |
| | Feature Group | 3 | 18 | 21 | 85.7% |
| RIGHT ON RED ARROW AFTER STOP | Control Group | 474 | 216 | 690 | 31.3% |
| | Feature Group | 196 | 570 | 766 | 74.4% |
| Total | Control Group | 675 | 611 | 1,286 | 47.5% |
| | Feature Group | 398 | 1,168 | 1,566 | 74.6% |

**Figure 14 - Comparison of compliant behaviors between feature and control sites**

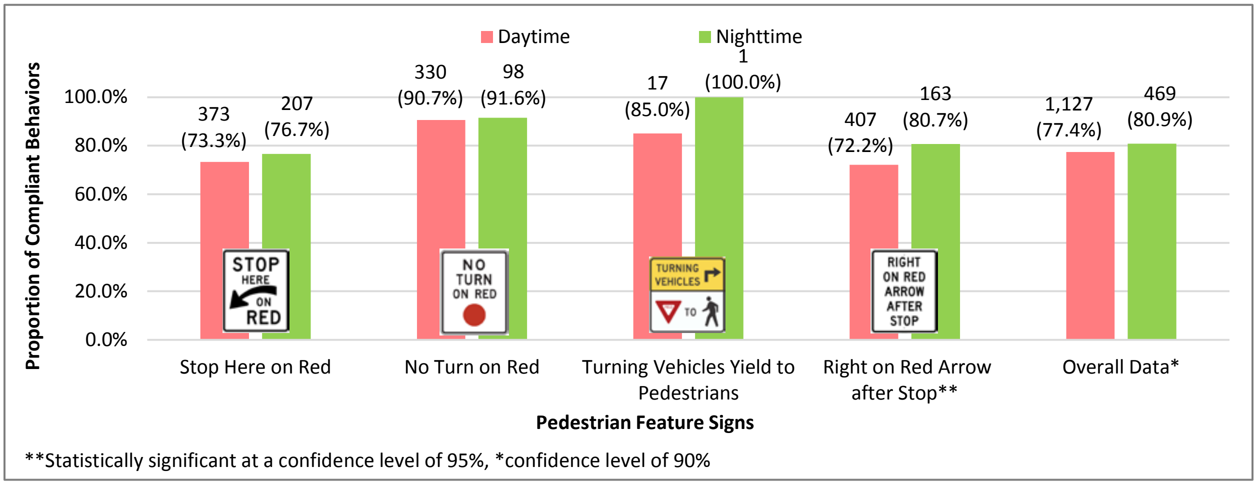
Three pedestrian features (“STOP HERE ON RED,” “TURNING VEHICLES YIELD TO PEDESTRIANS,” and “RIGHT ON RED ARROW AFTER STOP” signs) increased the compliant behaviors with the feature intention when compared to control groups. The largest percentage point change in proportion of compliant behavior is an increase of 43.1% by the “RIGHT ON RED ARROW AFTER STOP” feature (from 31.3% to 74.4%), followed by the percentage point increase of 19.0% from 66.7% to 85.7% for “TURNING VEHICLES YIELD TO PEDESTRIANS” feature, and the percentage point increase of 8.2% from 66.3% to 74.5% for “STOP HERE ON RED” feature. The difference for “STOP HERE ON RED” was significant at a confidence level of 90%, and the difference for “RIGHT ON RED ARROW AFTER STOP” was significant at a confidence level of 95%.

– The feature of "NO TURN ON RED" was not applied in this comparison due to the change in the definition of compliant behavior, since turning on red after stopping is allowed in the control group but not in the feature group.

– The overall percentage point change in the proportion of compliant behavior to the feature intention is an increase of 27.1% (from 47.5% to 74.6%) when compared to that at the control sites, and the difference was significant at a 95% confidence level.

### *6.1.3. Individual Analysis: Comparison of Compliant Behaviors by Time at Feature Sites*

Figure 15 compares driver compliant behaviors at feature sites by time, including daytime and nighttime.




| Pedestrian Feature Signs | Time | Non-Compliant Counts | Compliant Counts | Total Counts | % Compliant Behaviors |
|---|---|---|---|---|---|
| STOP HERE ON RED | Daytime | 136 | 373 | 509 | 73.3% |
| | Nighttime | 63 | 207 | 270 | 76.7% |
| NO TURN ON RED | Daytime | 34 | 330 | 364 | 90.7% |
| | Nighttime | 9 | 98 | 107 | 91.6% |
| TURNING VEHICLES YIELD TO PEDESTRIANS | Daytime | 3 | 17 | 20 | 85.0% |
| | Nighttime | 0 | 1 | 1 | 100.0% |
| RIGHT ON RED ARROW AFTER STOP | Daytime | 157 | 407 | 564 | 72.2% |
| | Nighttime | 39 | 163 | 202 | 80.7% |
| Total | Daytime | 330 | 1,127 | 1,457 | 77.4% |
| | Nighttime | 111 | 469 | 580 | 80.9% |

**Figure 15 - Comparison of compliant behaviors by time**

It shows that, overall, the proportion of compliant behavior is 77.4% in the daytime and 80.9% in the nighttime, indicating that drivers are more likely to comply with the pedestrian features during the nighttime, and the difference in proportion of compliant behaviors between these two time periods is significant at a 90% confidence interval.

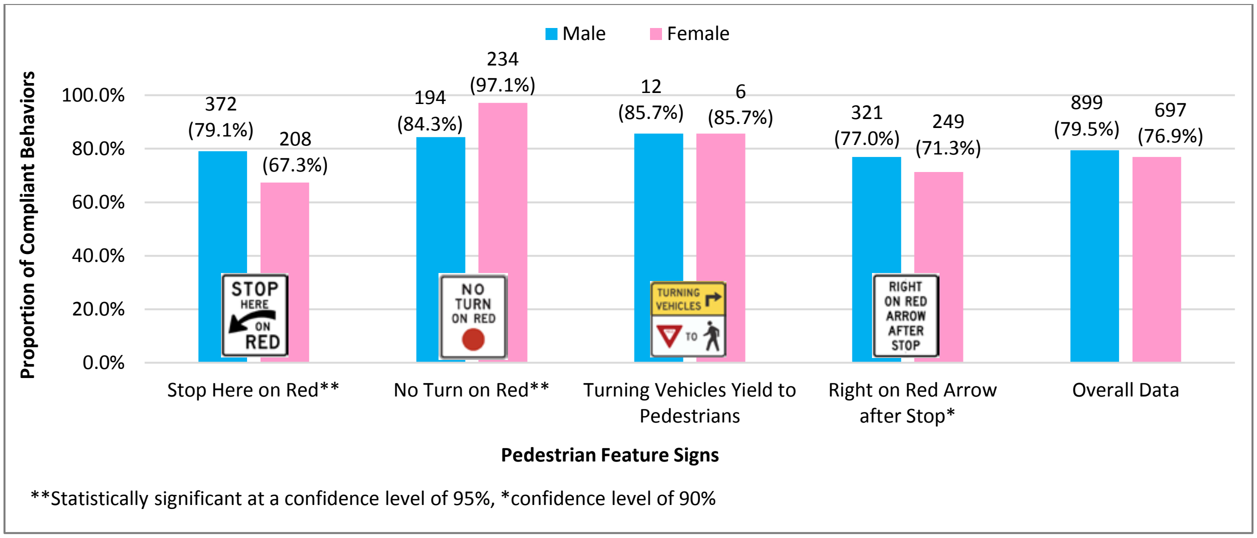
The proportion of compliant behavior increased from 73.6% to 76.7% for "STOP HERE ON RED," from 90.7% to 91.6% for "NO TURN ON RED," and from 85.0% to 100% for "TURNING VEHICLES YIELD TO PEDESTRIANS," but none of the increases is significant. The proportion of compliant behavior increased from 72.2% to 80.7% for "RIGHT ON RED ARROW AFTER STOP," and the increase is significant at a 95% confidence level.

A potential reason for the higher proportion of compliance at nighttime is that drivers have limited visibility at nighttime, and therefore tend to be more cautious on driving to reduce crash risk.

#### *6.1.4. Individual Analysis: Comparison of Compliant Behaviors by Gender at Feature Sites*

Figure 16 compares driver compliant behaviors at feature sites by driver gender.

- For the "STOP HERE ON RED" and "RIGHT ON RED ARROW AFTER STOP" features, female drivers (67.3% and 71.3%, respectively) were less likely to comply than male drivers (79.1% and 77.0%, respectively); the differences were significant at a 95% confidence level and a 90% confidence level, respectively.
- For the "NO TURN ON RED" feature, female drivers (97.1%) were more likely to comply with the feature than male drivers (84.3%); the difference was significant at a 95% confidence level.
- For the "TURNING VEHICLES YIELD TO PEDESTRIANS" feature, the proportions of compliance were the same between male and female drivers (85.7%).




| Pedestrian Feature Signs | Gender | Non-Compliant Counts | Compliant Counts | Total Counts | % Compliant Behaviors |
|---|---|---|---|---|---|
| STOP HERE ON RED | Female | 101 | 208 | 309 | 67.3% |
| | Male | 98 | 372 | 470 | 79.1% |
| NO TURN ON RED | Female | 7 | 234 | 241 | 97.1% |
| | Male | 36 | 194 | 230 | 84.3% |
| TURNING VEHICLES YIELD TO PEDESTRIANS | Female | 1 | 6 | 7 | 85.7% |
| | Male | 2 | 12 | 14 | 85.7% |
| RIGHT ON RED ARROW AFTER STOP | Female | 100 | 249 | 349 | 71.3% |
| | Male | 96 | 321 | 417 | 77.0% |
| Total | Female | 209 | 697 | 906 | 76.9% |
| | Male | 232 | 899 | 1,131 | 79.5% |

**Figure 16 - Comparison of compliant behaviors by gender**

### *6.1.5. Individual Analysis: Comparison of Compliant Behaviors by Age at Feature Sites*

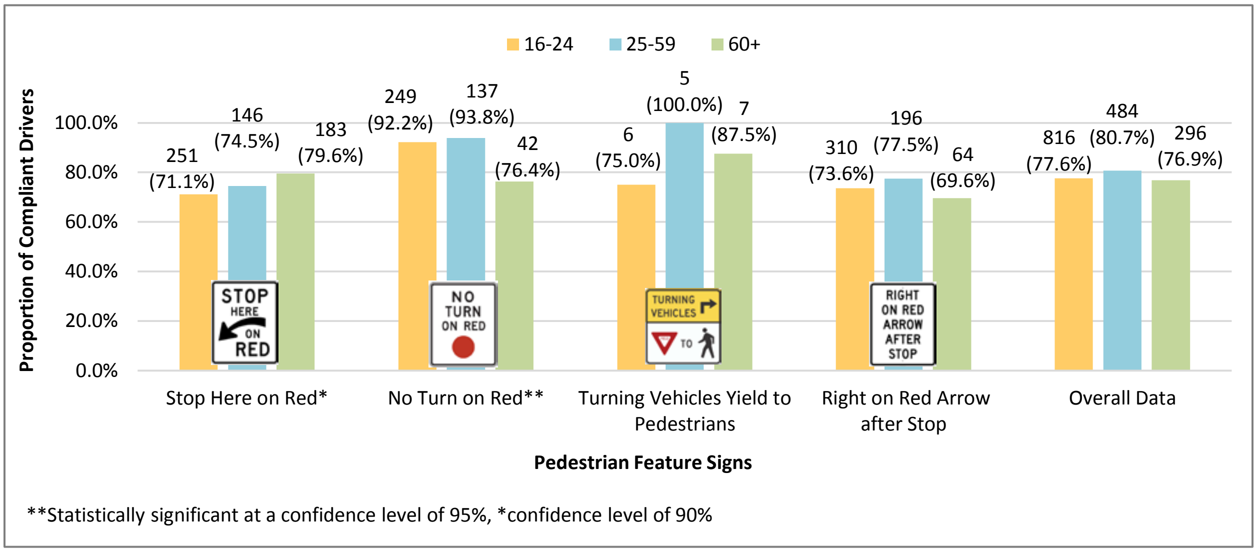
Figure 17 compares the driver compliant behaviors at feature sites by age. Overall, mid-age (25–59) drivers demonstrate the highest proportion of compliant behavior (80.7%), followed by younger drivers (16–24, 77.6%) and older drivers (ages 60+, 76.9%).

– At sites with a “STOP HERE ON RED” sign, older drivers (ages 60+) showed the highest proportion of compliance (79.6%), followed by mid-age drivers (74.5%) and younger drivers (71.1%). The largest difference among age groups was significant at a 90% confidence level.

– At sites with a “NO TURN ON RED” sign, mid-age drivers (ages 25–59) showed the highest proportion of compliance (93.8%), followed by younger drivers (92.2%) and older drivers (76.4%). The largest difference among age groups was significant at a 95% confidence level.

– At sites with a “TURNING VEHICLES YIELD TO PEDESTRIANS” sign, mid-age drivers (ages 25–59) completely complied with the feature (100%), followed by older drivers (87.5%) and younger drivers (75.0%). The significance test was not applicable due to the limited sample size.

– At sites with a "RIGHT ON RED ARROW AFTER STOP" signs, mid-age drivers (ages 25–59) showed the highest proportion of compliance (77.5%), followed by younger drivers (73.6%) and older drivers (69.6%). No significant difference among the three age groups was detected for this feature.

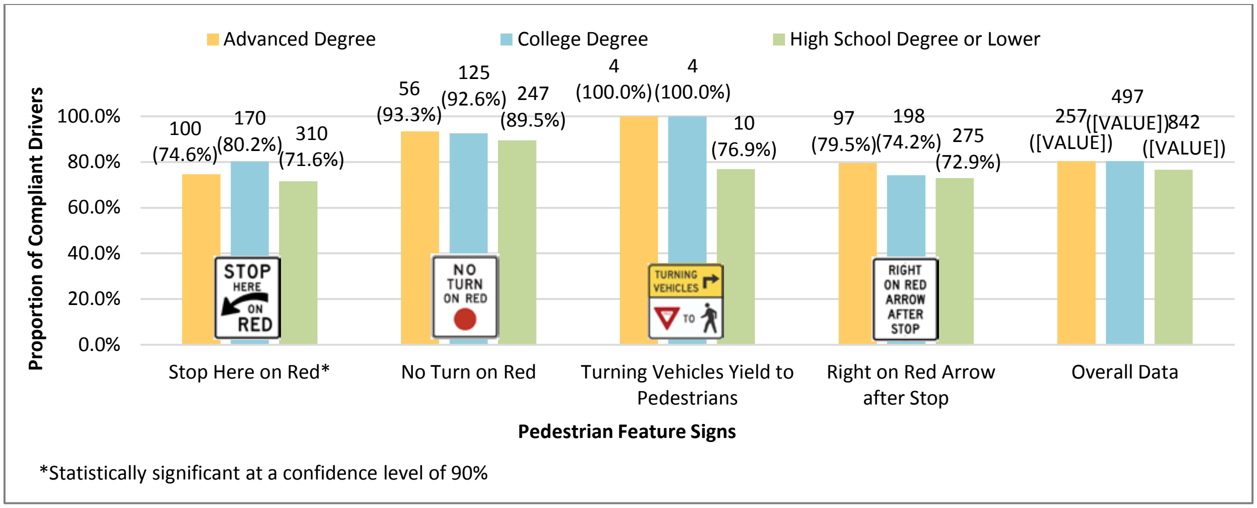



| Pedestrian Feature Signs | Age Group | Non-Compliant Counts | Compliant Counts | Total Counts | % Compliant Behaviors |
|---|---|---|---|---|---|
| STOP HERE ON RED | 16–24 | 102 | 251 | 353 | 71.1% |
| | 25–59 | 50 | 146 | 196 | 74.5% |
| | 60+ | 47 | 183 | 230 | 79.6% |
| NO TURN ON RED | 16–24 | 21 | 249 | 270 | 92.2% |
| | 25–59 | 9 | 137 | 146 | 93.8% |
| | 60+ | 13 | 42 | 55 | 76.4% |
| TURNING VEHICLES YIELD TO PEDESTRIANS | 16–24 | 2 | 6 | 8 | 75.0% |
| | 25–59 | 0 | 5 | 5 | 100.0% |
| | 60+ | 1 | 7 | 8 | 87.5% |
| RIGHT ON RED ARROW AFTER STOP | 16–24 | 111 | 310 | 421 | 73.6% |
| | 25–59 | 57 | 196 | 253 | 77.5% |
| | 60+ | 28 | 64 | 92 | 69.6% |
| Total | 16–24 | 236 | 816 | 1,052 | 77.6% |
| | 25–59 | 116 | 484 | 600 | 80.7% |
| | 60+ | 89 | 296 | 385 | 76.9% |

**Figure 17 - Comparison of compliant behaviors by age**

### *6.1.6. Individual Analysis: Comparison of Compliant Behaviors by Education Level at Feature Sites*

Figure 18 compares the driver compliant behaviors at feature sites by education level.




| Pedestrian Feature Signs | Education Level | Non-Compliant Counts | Compliant Counts | Total Counts | % Compliant Behaviors |
|---|---|---|---|---|---|
| STOP HERE ON RED | Advanced Degree | 34 | 100 | 134 | 74.6% |
| | College Degree | 42 | 170 | 212 | 80.2% |
| | High School Degree or Lower | 123 | 310 | 433 | 71.6% |
| NO TURN ON RED | Advanced Degree | 4 | 56 | 60 | 93.3% |
| | College Degree | 10 | 125 | 135 | 92.6% |
| | High School Degree or Lower | 29 | 247 | 276 | 89.5% |
| TURNING VEHICLES YIELD TO PEDESTRIANS | Advanced Degree | 0 | 4 | 4 | 100.0% |
| | College Degree | 0 | 4 | 4 | 100.0% |
| | High School Degree or Lower | 3 | 10 | 13 | 76.9% |
| RIGHT ON RED ARROW AFTER STOP | Advanced Degree | 25 | 97 | 122 | 79.5% |
| | College Degree | 69 | 198 | 267 | 74.2% |
| | High School Degree or Lower | 102 | 275 | 377 | 72.9% |
| Total | Advanced Degree | 63 | 257 | 320 | 80.3% |
| | College Degree | 121 | 497 | 618 | 80.4% |
| | High School Degree or Lower | 257 | 842 | 1,099 | 76.6% |

**Figure 18 - Comparison of compliant behaviors by education level**

– At sites with “NO TURN ON RED” and “RIGHT ON RED ARROW AFTER STOP” signs, drivers with an advanced degree showed the highest proportion of compliance, followed drivers with a college degree and drivers with a high school degree or lower.

– At sites with “STOP HERE ON RED” sign, drivers with a college degree showed the highest proportion of compliance (80.2%), followed by drivers with an advanced degree (74.6%) and drivers with a high school degree or lower (71.6%). The largest difference among age groups is significant at a 90% confidence level.

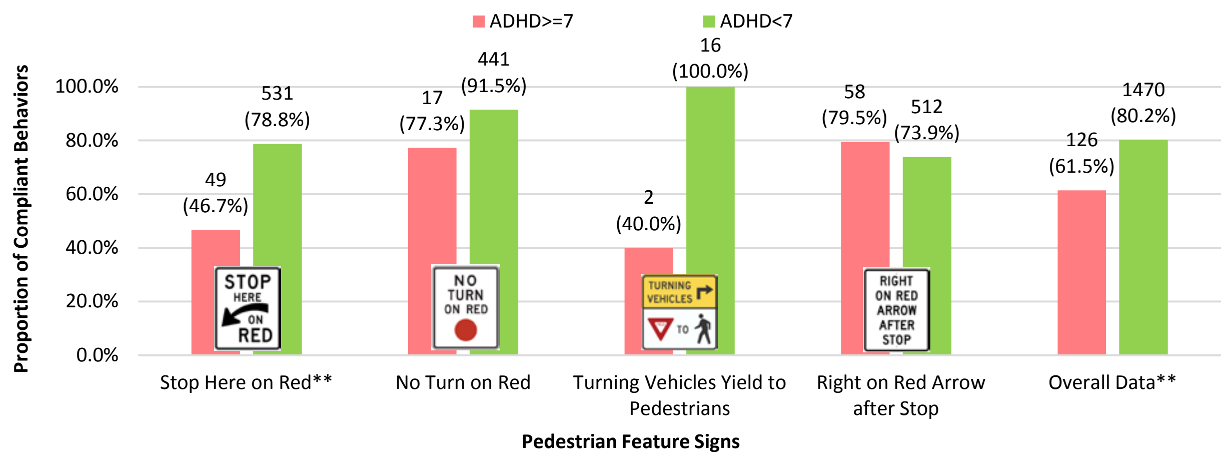
– At sites with “TURNING VEHICLES YIELD TO PEDESTRIANS” sign, both drivers with an advanced degree and drivers with a college degree completely complied with the feature (100.0%).

- Overall, drivers with college degrees and advanced degrees demonstrated comparable proportions of compliant behavior (80.4% and 80.3%, respectively), and drivers with high school degrees or lower showed the lowest proportion of compliant behavior (76.6%) among all groups, indicating that higher education level generally leads to a higher proportion of driver compliant behaviors at sites with pedestrian features.

### *6.1.7. Individual Analysis: Comparison of Compliant Behaviors by ADHD Level at Feature Sites*

Figure 19 compares the driver compliant behaviors at feature sites by attention-deficit/ hyperactivity disorder (ADHD) level. ADHD is a brain disorder marked by an ongoing pattern of inattention and/or hyperactivity-impulsivity that interferes with functioning or development. An ADHD score of 7 or higher indicates a driver with possible ADHD symptoms, which may pose a negative influence on pedestrian feature compliant behavior and driving safety.

- At sites with “STOP HERE ON RED” signs, drivers without possible ADHD symptoms showed a higher proportion of compliance (78.8%) than their counterparts (46.7%), and the difference in proportion of compliance between these two groups was significant at a 95% confidence level.
- At sites with “NO TURN ON RED” and “TURNING VEHICLE YIELD TO PEDESTRIAN” signs, drivers without possible ADHD symptoms showed a higher proportion of compliance (91.5% and 100.0% respectively) than their counterparts (77.3% and 40.0%, respectively). The significance test was not applicable due to the limited data size for “ADHD>=7” group.
- At sites with a “RIGHT ON RED ARROW AFTER STOP” sign, drivers with possible ADHD symptoms showed a higher proportion of compliance (79.5%) than their counterparts (73.9%), but the difference in proportion of compliance was not significant.
- Overall, drivers without possible ADHD symptoms had a higher proportion of compliance (80.2%) than their counterpart groups (61.5%), and the difference was statistically significant at 95% significance level.



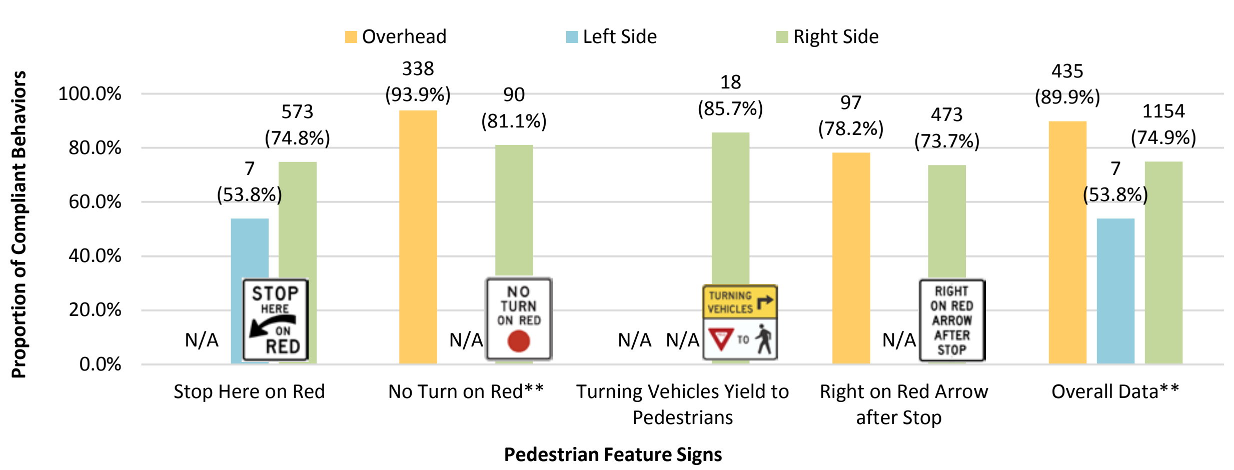

**Statistically significant at a confidence level of 95%

| Pedestrian Feature Signs | ADHD Level | Non-Compliant Counts | Compliant Counts | Total Counts | % Compliant Behaviors |
|---|---|---|---|---|---|
| STOP HERE ON RED | ADHD>=7 | 56 | 49 | 105 | 46.7% |
| | ADHD<7 | 143 | 531 | 674 | 78.8% |
| NO TURN ON RED | ADHD>=7 | 5 | 17 | 22 | 77.3% |
| | ADHD<7 | 38 | 411 | 449 | 91.5% |
| TURNING VEHICLES YIELD TO PEDESTRIANS | ADHD>=7 | 3 | 2 | 5 | 40.0% |
| | ADHD<7 | 0 | 16 | 16 | 100.0% |
| RIGHT ON RED ARROW AFTER STOP | ADHD>=7 | 15 | 58 | 73 | 79.5% |
| | ADHD<7 | 181 | 512 | 693 | 73.9% |
| Total | ADHD>=7 | 79 | 126 | 205 | 61.5% |
| | ADHD<7 | 362 | 1,470 | 1,832 | 80.2% |

**Figure 19 - Comparison of compliant behaviors by ADHD level**

### *6.1.8. Individual Analysis: Comparison of Compliant Behaviors by Sign Locations at Feature Sites*

Figure 20 compares driver compliant behaviors at feature sites by feature sign locations, where "N/A" indicates that the corresponding location is not applicable to that pedestrian feature sign.




**Statistically significant at a confidence level of 95%

| Pedestrian Feature Signs | Sign Location | Non-Compliant Counts | Compliant Counts | Total Counts | % Compliant Behaviors |
|---|---|---|---|---|---|
| STOP HERE ON RED | Overhead | N/A | | | |
| | Left Side | 6 | 7 | 13 | 53.8% |
| | Right Side | 193 | 573 | 766 | 74.8% |
| NO TURN ON RED | Overhead | 22 | 338 | 360 | 93.9% |
| | Left Side | N/A | | | |
| | Right Side | 21 | 90 | 111 | 81.1% |
| TURNING VEHICLES YIELD TO PEDESTRIANS | Overhead | N/A | | | |
| | Left Side | N/A | | | |
| | Right Side | 3 | 18 | 21 | 85.7% |
| RIGHT ON RED ARROW AFTER STOP | Overhead | 27 | 97 | 124 | 78.2% |
| | Left Side | N/A | | | |
| | Right Side | 169 | 473 | 642 | 73.7% |
| Total | Overhead | 49 | 435 | 484 | 89.9% |
| | Left Side | 6 | 7 | 13 | 53.8% |
| | Right Side | 386 | 1,154 | 1,540 | 74.9% |

**Figure 20 - Comparison of compliant behaviors by feature sign location**

– Two locations were applied to "STOP HERE ON RED" signs, including left side (median) and right side (roadside), where right side is the dominant location. It shows that "STOP HERE ON RED" signs on the right roadside are more effective in improving driver compliance (74.8% vs. 53.8%). The significance test is not applicable due to the limited number of records for left-side signs.

– Two locations were applied to "NO TURN ON RED" signs, including overhead and right side (roadside), where overhead is the dominant location. It shows that overhead "NO TURN ON RED" signs are more effective in improving driver compliance (93.9% vs. 81.1%), and this difference is significant at the 95% significance level.

– Two locations were applied to "RIGHT ON RED ARROW AFTER STOP" signs, including overhead and right side (roadside), where roadside is the dominant location. It shows that overhead "RIGHT ON RED ARROW AFTER STOP" signs are more effective in improving driver compliance (78.2% vs. 73.7%), but this difference is not significant.

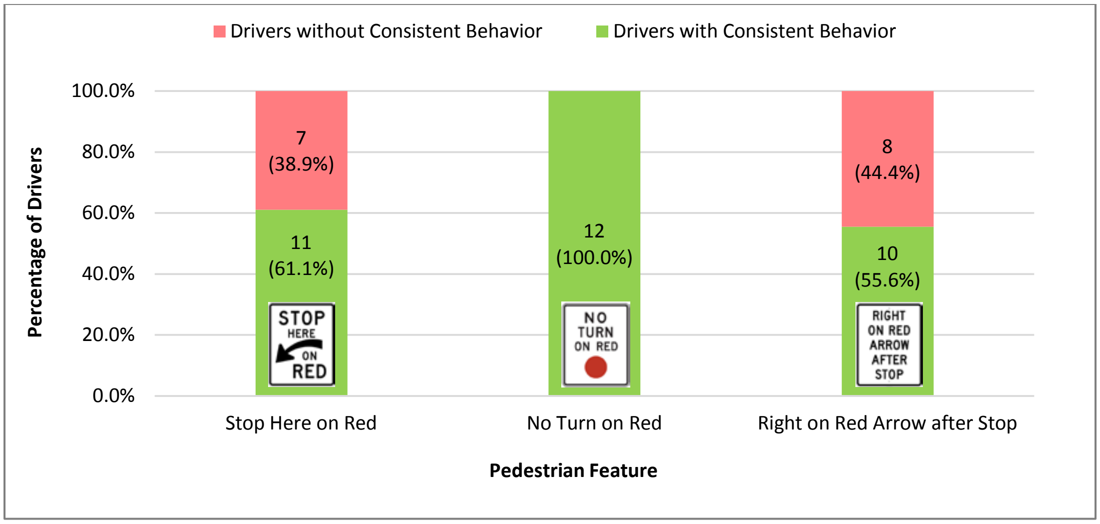
– Overall, these three locations induce varying proportions of compliant behaviors. The significance test was conducted for overhead and right-side locations; left-side records were excluded due to limited data size. The difference is significant at the 95% significance level, and overhead signs produce the highest proportion of compliant behaviors.

### *6.1.9. Individual Analysis: Driver Behavior Consistency by Feature*

In Phase 2, a total of 2,037 valid events from a total of 361 unique drivers were included in the analysis. Therefore, on average, each driver participated in 5.6 events. This provides a potential opportunity to examine driver compliance/non-compliant behavior consistency. To draw valid conclusions, drivers who participated in at least 10 events for a certain feature were included in this analysis. Therefore, a total of 48 drivers for three features (“STOP HERE ON RED,” NO TURN ON RED,” and “RIGHT ON RED ARROW AFTER STOP” signs) were used in this analysis.

In this analysis, a consistent behavior is defined as either compliant or non-compliant behavior regarding the feature sign with the dominant proportion (which is larger)—i.e., if a driver performs more compliant behavior than non-compliant behavior regarding a feature sign, it is considered that compliance is the consistent behavior and non-compliance is the “outlier” behavior. On the other hand, if a driver performs more non-compliant behavior than compliant behavior regarding a feature, it is considered that non-compliance is the consistent behavior and compliance is the “outlier” behavior. To evaluate driver behavior consistency, given the proportion of compliant behavior for each pedestrian feature shown in Figure 3, a threshold value of 75.0% was selected and compared with the proportion of consistent behavior for each driver.

Figure 21 summarizes the number of drivers, number of events, number and percentage of drivers exhibiting consistent behavior for each feature. Due to the limited number of records, data for “TURNING VEHICLES YIELD TO PEDESTRIANS” were not included.




| Pedestrian Feature Signs | Non-Consistent Drivers | Consistent Drivers | Total Drivers | % Consistent Drivers |
|---|---|---|---|---|
| STOP HERE ON RED | 7 | 11 | 18 | 61.1% |
| NO TURN ON RED | 0 | 12 | 12 | 100.0% |
| RIGHT ON RED ARROW AFTER STOP | 8 | 10 | 18 | 55.6% |

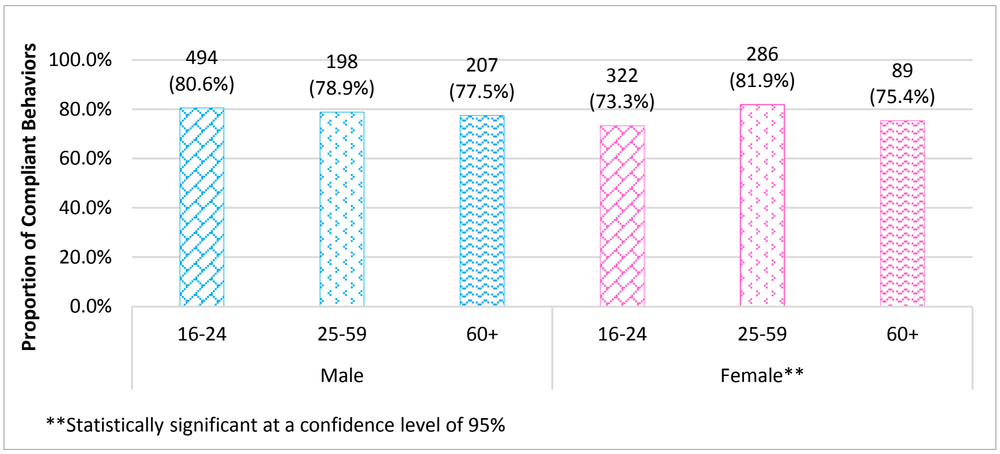
**Figure 21 - Comparison of driver behavior consistency by feature**

- In total, 11 drivers behaved consistently at intersections with a “STOP HERE ON RED” feature, accounting for 61.1% of the 18 drivers included. Detailed examination also reveals that, among these 11 drivers, 10 had a compliance rate of 75.0% or higher, and 1 had a compliance rate of 2.9%, indicating consistent non-compliant behavior. It is also indicated that most of the non-compliant behavior involved “stopping past the stop line” or even “blocking crosswalk.” These findings indicate that half of these drivers performed consistently at intersections with a “STOP HERE ON RED” pedestrian feature, and education and enforcement are needed to emphasize “stopping before stop line” behavior to reduce potential conflicts with pedestrians and increase traffic safety.
- All of 12 drivers behaved consistently at intersections with a “NO TURN ON RED” feature, with a compliance rate of 90.9% or higher. Detailed examination also reveals that 9 drivers had a 100.0% compliance rate. These findings are consistent with the high overall compliance rate for all drivers regarding “NO TURN ON RED” pedestrian features and indicate that this sign is very effective.
- In total, 10 drivers behaved consistently at intersections with a “RIGHT ON RED ARROW AFTER STOP” feature, accounting for 55.6% of the 18 drivers included. Detailed examination reveals that for most of the non-compliant behavior, drivers performed a rolling stop rather than a full stop while checking for pedestrians and conflicting traffic. These findings indicate that education and enforcement are needed to emphasize the “full stop, observe, and turn” behavior to reduce potential conflicts with pedestrians and conflicting traffic and increase traffic safety.

### *6.1.10. Overall Analysis: Consistency of Driver Compliance Performance*

Figure 22 shows the overall consistency comparison of driver compliant behaviors by age within each gender.

The variation among different groups for male and female were compared. Male drivers demonstrated comparable proportions of compliant behaviors with pedestrian feature signs among age groups (80.6 vs.78.9% vs.77.5%). Female drivers showed a larger variation for proportions of compliant behaviors among age groups. Younger (ages 16–24) female drivers exhibited the lowest proportion of compliant behaviors (73.3%), and mid-aged (ages 25–59) female drivers exhibited the highest proportion of compliant behaviors (81.9%), and the difference is significant at a 95% confidence level.

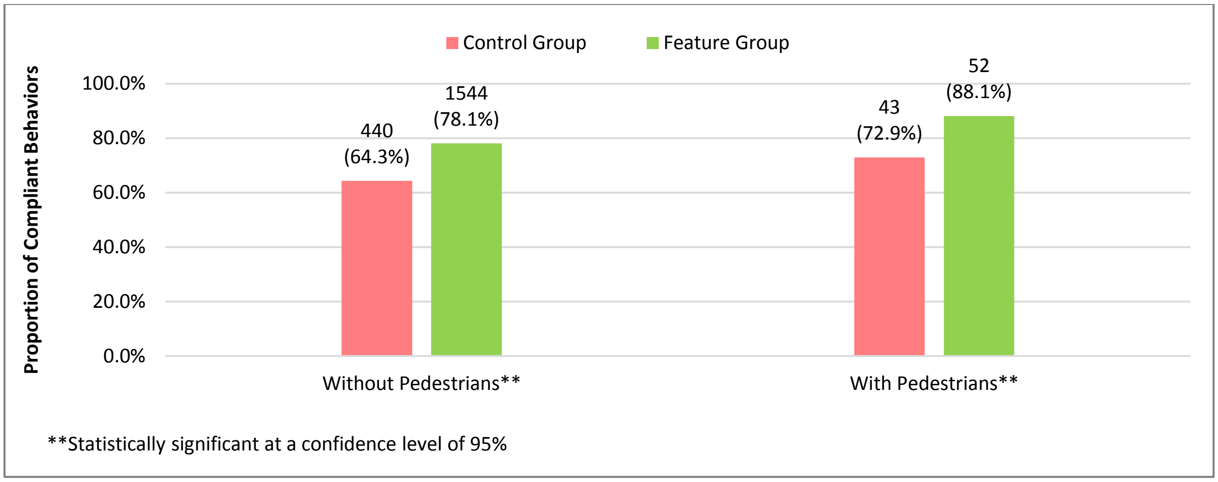



| Driver Gender | Age Group | Non-Compliant Counts | Compliant Counts | Total Counts | % Compliant Behaviors |
|---|---|---|---|---|---|
| Male | 16–24 | 119 | 494 | 613 | 80.6% |
| | 25–59 | 53 | 198 | 251 | 78.9% |
| | 60+ | 60 | 207 | 267 | 77.5% |
| Female | 16–24 | 117 | 322 | 439 | 73.3% |
| | 25–59 | 63 | 286 | 349 | 81.9% |
| | 60+ | 29 | 89 | 118 | 75.4% |

**Figure 22 - Consistency comparison of compliant behaviors by gender and age**

### *6.1.11. Overall Analysis: Impacts of Pedestrian Presence*

Figure 23 shows the overall comparison of the compliant behaviors with and without pedestrians between feature and control groups.




| Pedestrian Presence | Comparison Group | Non-Compliant Counts | Compliant Counts | Total Counts | % Compliant Behaviors |
|---|---|---|---|---|---|
| Without Pedestrians | Control Group | 244 | 440 | 684 | 64.3% |
| | Feature Group | 434 | 1,544 | 1,978 | 78.1% |
| With Pedestrians | Control Group | 16 | 43 | 59 | 72.9% |
| | Feature Group | 7 | 52 | 59 | 88.1% |

**Figure 23 - Comparison of compliant behaviors with/without pedestrian presence**

- The pedestrian features lead to a percentage point change of 13.8% (from 64.3% to 78.1%) in the proportion of compliant behavior when pedestrians were not present at intersections. The increase was statistically significant at a 95% confidence level. This finding is very important, indicating that drivers most likely will comply with pedestrian features at feature sites even though there are no pedestrians present or drivers do not see them.
- Drivers were generally sensitive to pedestrian presence at both feature sites and control sites. The compliance proportions for both groups were higher when pedestrians were present than those when pedestrians were absent.
- The pedestrian features lead to a percentage point change of 15.2% (from 72.9% to 88.1%) in the proportion of compliant behavior when pedestrians were present than that at control sites. The increase was also statistically significant at a 95% confidence level.

### *6.1.12. Overall Analysis: Impacts of Driver Risk and Distraction Characteristics on Compliant Behaviors*

Answers to the Risk-Taking Questionnaire were used to assess the following 12 risky and distractive behaviors:

- Running red light
- Sleepy driving
- Sudden lane change
- Illegal turn

- Tailgating
- Failure to adjust speed under adverse conditions
- Accelerating at yellow signal
- Drunk driving
- Driving in a rage
- Speeding by 20 mph or more
- Not yielding to pedestrians
- Rolling through a stop sign

Possible responses to each question were 0–Never, 1–Rarely, 2–Sometimes, or 3–Often. A comprehensive Risk Score was calculated based on the responses, and the weight for each question was defined based on engineering judgment. For example, sleepy driving behavior usually leads to a severe crash outcome and, therefore, was assigned a higher weight value than most other risky behaviors.

$$\begin{aligned}\text{Risk Score} = {} & \text{Run red light} + 2 \times \text{Sleepy driving} + \text{Sudden lane change} + \\ & \text{Illegal turn} + \text{Tailgate} + \text{Failure to adjust speed under adverse conditions} + 2 \times \\ & \text{Accelerating at yellow signal} + 2 \times \text{Drunk driving} + \text{Driving in a rage} + 2 \times \\ & \text{Speeding by 20 mph or more} + \text{Not yielding to pedestrians} + \\ & \text{Rolling through stop sign} \end{aligned} \tag{2}$$

Using this definition, a Risk Score has a minimum theoretical value of 0 and a maximum theoretical value of 48. However, it is almost impossible for a driver to reach the maximum Risk Score in actual scenarios. In this analysis, the minimum Risk Score was 0 and the maximum score was 30 among all drivers. Therefore, to appropriately evaluate driver risk levels and maintain a comparable sample size in each risk group, risk levels were defined as follows:

- High Risk Group – Risk Score greater than or equal to 16
- Low Risk Group – Risk Score less than 16

Responses to three questions related to driver distraction were used to determine the level of driver distraction that included:

- Secondary task (use cellphone, eat/drink, apply makeup, read, smoke) while driving
- Eyes off road to change CD
- Eyes off road to talk to passengers

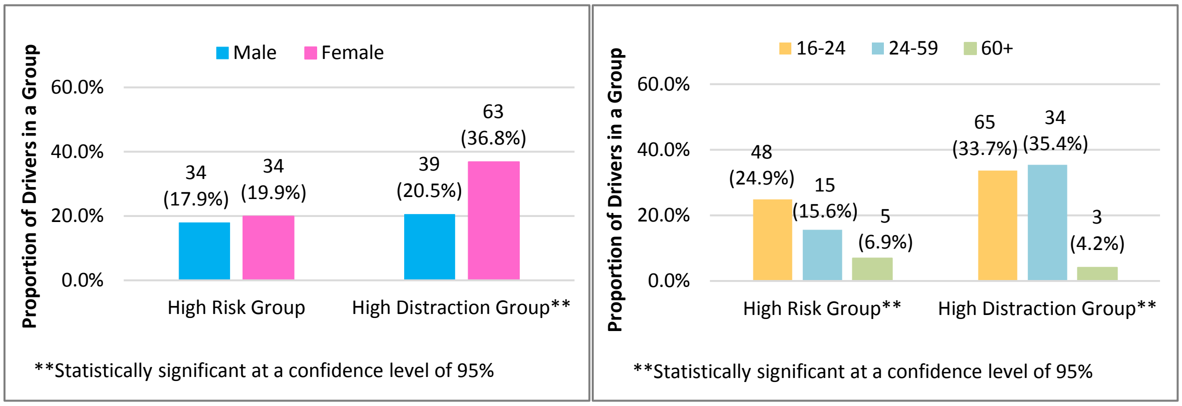
Possible responses to each question were 0–Never, 1–Rarely, 2–Sometimes, or 3–Often. A comprehensive Distraction Score was calculated based on the responses, and the weight for each question was defined based on engineering judgment. For example, secondary tasks while driving, such as using a cellphone, eating or drinking, etc., occur more often than the other two types of distractive behaviors and, therefore, were assigned a higher weight value than the other two.

$$\text{Distraction Score} = 3 \times \text{Secondary task while driving} + 1.5 \times \text{Eyes off road to change CD} + \text{Eyes off road to talk to passengers} \quad (3)$$

Using this definition, the Distraction Score has a minimum theoretical value of 0 and a maximum theoretical of 16.5. In the Phase 2 study with actual scenarios, the minimum Risk Score was 0 and the maximum score was 16.5 among all drivers. It was assumed in this study that a driver who answered "2–Sometimes" to each of the three questions and obtained a total Distraction Score of 11, is considered a highly distracted driver. A Distraction Score of 11 was selected as the threshold value to define driver distraction levels as follows:

- High Distraction Group – Distraction Score greater than or equal to 11
- Low Distraction Group – Distraction Score less than 11

Chi-square tests were conducted to compare the proportion of drivers belonging to a group (based on self-evaluation) by driver characteristics, as shown in Figure 24.




| Driver Demographics | | Risk Level | | | Distraction Level | | |
|---|---|---|---|---|---|---|---|
| | | High Risk Counts | Total Counts | % in High Risk Group | High Distraction Counts | Total Counts | % in High Distraction Group |
| Gender | Female | 34 | 171 | 19.9% | 63 | 171 | 36.8% |
| | Male | 34 | 190 | 17.9% | 39 | 190 | 20.5% |
| Age Group | 16–24 | 48 | 193 | 24.9% | 65 | 193 | 33.7% |
| | 25–59 | 15 | 96 | 15.6% | 34 | 96 | 35.4% |
| | 60+ | 5 | 72 | 6.9% | 3 | 72 | 4.2% |

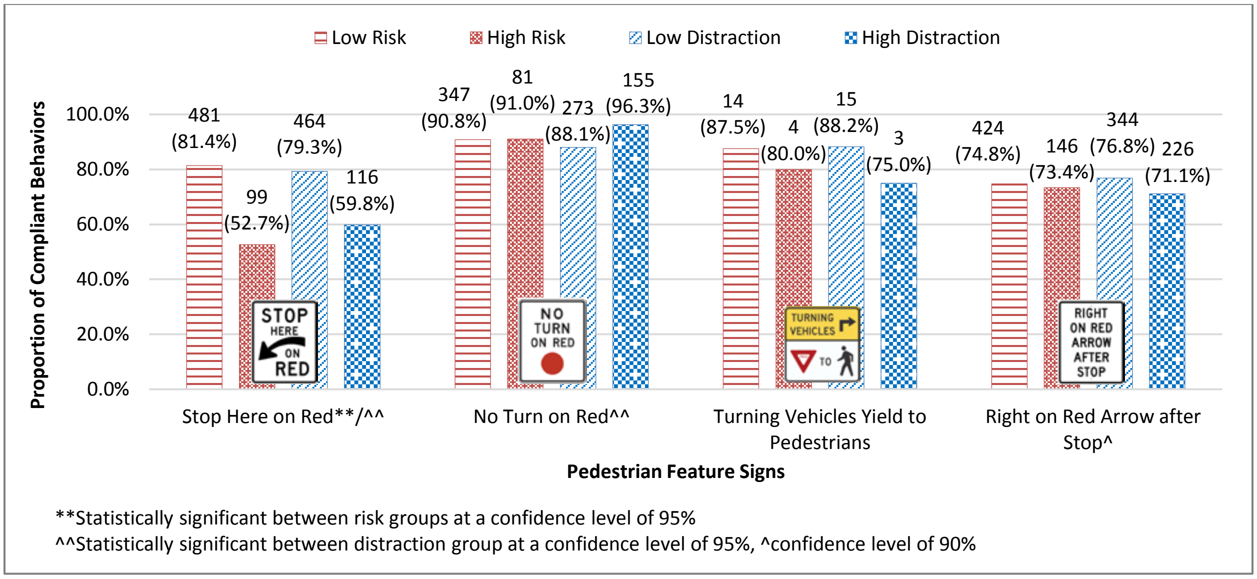
**Figure 24 - Comparison of risk and distraction levels by gender and age**

- Per self-evaluation, more female drivers were classified into the groups of "High Risk" (19.9% vs. 17.9%) and "High Distraction" (36.8% vs. 20.5%) than male drivers. The difference was significant in terms of distraction at a 95% confidence level.
- Per self-evaluation, younger drivers (ages 16–24) took significantly more risks than those in age groups 25–59 and older (60+) drivers; younger drivers (ages 16–24) and mid-age drivers (ages 25–59) were significantly more likely to be distracted than older drivers (ages 60+).

- Per self-evaluation, older drivers (ages 60+) took significantly fewer risks and were less likely to be distracted than other drivers.

To link subjective risk and distraction to objective behavior observations, the compliant behaviors were compared by risk and distraction level for all four feature signs. The comparison results are illustrated in Figure 25.

- At sites with a “STOP HERE ON RED” sign, drivers in the “Low Risk” (81.4% vs. 52.7%) or “Low Distraction” (79.3% vs. 59.8%) groups were more likely to comply with the sign than were those in the corresponding counterpart group. Both of the differences in terms of proportion of compliance were significant at a 95% confidence level.
- At sites with a “NO TURN ON RED” sign, drivers in the “High Risk” and “Low Risk” groups produced comparable proportions of compliance (90.8% vs. 91.0%). Drivers in the “High Distraction” group (96.3%) were more likely to comply with the sign than drivers in the “Low Distraction” group (88.1%); the difference in terms of proportion of compliance was significant at a 95% confidence level. This is reasonable because highly-distracted drivers are more likely to become involved in secondary tasks, such as checking their cell phones, eating, etc., and they are more likely to stop at this feature sign to perform these activities while ensuring driving safety at the same time.
- At sites with a “TURNING VEHICLES YIELD TO PEDESTRIANS” sign, drivers in the “Low Risk” (87.5% vs. 80.0%) or “Low Distraction” (88.2% vs.75.0%) groups were more likely to comply with the sign than those in the corresponding counterpart group. Due to a small sample size for this feature, it was difficult for a solid significance test.
- At sites with a “RIGHT TURN ON RED ARROW AFTER STOP” sign, drivers in the “Low Risk” group (74.8%) were more likely to comply with the sign than those in the “High Risk” (73.4%) group, but the difference was not significant. Drivers in the “Low Distraction” (76.8%) group were more likely to comply with the sign than those in the “High Distraction” (71.1%) group; the difference in terms of proportion of compliance was significant at a 90% confidence level.




| Pedestrian Feature Signs | Comparison Group | Non-Compliant Counts | Compliant Counts | Total Counts | % Compliant Behaviors |
|---|---|---|---|---|---|
| STOP HERE ON RED | High Risk | 89 | 99 | 188 | 52.7% |
| | Low Risk | 110 | 481 | 591 | 81.4% |
| | High Distraction | 78 | 116 | 194 | 59.8% |
| | Low Distraction | 121 | 464 | 585 | 79.3% |
| NO TURN ON RED | High Risk | 8 | 81 | 89 | 91.0% |
| | Low Risk | 35 | 347 | 382 | 90.8% |
| | High Distraction | 6 | 155 | 161 | 96.3% |
| | Low Distraction | 37 | 273 | 310 | 88.1% |
| TURNING VEHICLES YIELD TO PEDESTRIANS | High Risk | 1 | 4 | 5 | 80.0% |
| | Low Risk | 2 | 14 | 16 | 87.5% |
| | High Distraction | 1 | 3 | 4 | 75.0% |
| | Low Distraction | 2 | 15 | 17 | 88.2% |
| RIGHT ON RED ARROW AFTER STOP | High Risk | 53 | 146 | 199 | 73.4% |
| | Low Risk | 143 | 424 | 567 | 74.8% |
| | High Distraction | 92 | 226 | 318 | 71.1% |
| | Low Distraction | 104 | 344 | 448 | 76.8% |

**Figure 25 - Comparison of compliant behaviors by risk and distraction levels**

## 6.2. Variable Impact Analysis Results

Given the binary response regarding driver compliance at pedestrian features, the GLMM model was used in this study to identify the significant factors affecting driver compliant behavior at pedestrian features and their individual and heterogeneous influence on driver compliant behavior distribution while holding other factors constant. All the factors listed above, including pedestrian feature type, event time, driver gender, driver age group, driver education level, driver potential ADHD symptoms, pedestrian presence or absence at intersections, and driver risk and distraction levels were included in the analysis. The GLMM modeling results were illustrated in

Table 6.

**Table 6 - GLMM Model Results on Driver Compliant Behavior at Pedestrian Features**

| Parameter | Estimated Mean. | Standard Error | P-value |
|---|---|---|---|
| *Fixed Effects* | | | |
| ***Constant (Intercept)***[a] | **0.946** | **0.296** | **0.001** |
| *Feature Group* | | | |
| STOP HERE ON RED | 0.801 | 0.122 | 0.507 |
| **NO TURN ON RED**[a] | **1.228** | **0.182** | **$1.38e^{-11}$** |
| TURNING VEHICLES YIELD TO PEDESTRIANS | 0.0004 | 0.827 | 0.999 |
| RIGHT ON RED ARROW AFTER STOP[b] | - | - | - |
| *Gender group* | | | |
| **Male**[a] | **0.914** | **0.114** | **0.087** |
| Female[b] | - | - | - |
| *Age Group* | | | |
| Young (16-24) | -0.149 | 0.133 | 0.262 |
| **Old (60 or older)**[a] | **-0.300** | **0.171** | **0.079** |
| Mid-age (25-59)[b] | - | - | - |
| *Pedestrian Presence* | | | |
| **Presence**[a] | **0.892** | **0.535** | **0.095** |
| Absence[b] | - | - | - |
| *Risk Level* | | | |
| **High Risk**[a] | **-0.280** | **0.117** | **0.017** |
| Low Risk[b] | - | - | - |
| *Random Effects* | | | |
| ADHD Level (2 Groups), Variance: 0.1212, Standard Deviation: 0.3482 | | | |
| **Log Likelihood** | -1,014.3 | | |

[a] *Significant variables at 90% confidence level are marked in bold.*
[b] *Reference category for GLMM modeling.*

A number of research findings could be summarized from these results:

– In this study, the ADHD symptom is based on driver self-evaluation and is not identified. In addition, ADHD symptoms cover a wide-range of mental-related behaviors, such as distractibility, hypersensitivity, or forgetfulness, which may pose various heterogeneous influence on driver compliant behavior. Additionally, in the analyze dataset, it is found that the data records associated with potential ADHD symptoms account for 10.06% of all the records (205 out of 2037), while the actual ADHD symptom for overall population is unknown. Therefore, ADHD is treated as the random effect in the modeling process.

- The estimated intercept coefficient is positive and is equal to 0.946, indicating that without any other factor considered drivers overall are in favor of compliance with traffic rules at signalized intersections, and this effect is significant at 95% confidence level.
- "RIGHT ON RED ARROW AFTER STOP" is treated as the base category when modeling the influence of different pedestrian features, given the fact in Figure 13 that the proportion of driver compliant behavior is the lowest (74.4%) among all the four features. It shows in Table 1 that all of the estimated coefficients are positive for the other three signs, indicating that comparing with "RIGHT ON RED ARROW AFTER STOP," all the other three features tend to increase driver compliant behavior at signalized intersection, which is consistent with our findings in Figure 13. The coefficient for "NO TURN ON RED" is the largest in magnitude among all the four features and is significant at 95% confidence level, which is consistent with the fact that drivers have highest proportion of compliance at this pedestrian feature. The estimated coefficients for "STOP HERE ON RED" and "TURNING VEHICLES YIELD TO PEDESTRIANS" are not significant at a minimum of 90% confidence interval.
- It is found that male drivers tend to have a higher probability of compliant behavior to pedestrian features, as shown by the positive coefficient equal to 0.914, which is statistically significant at 90% confidence level. This result is also consistent with the comparison result shown in Figure 16.
- Taking mid-age group as the reference category, both young age group (16–24) and old age group (60 or older) tend to reduce the probability of driver compliant behavior at pedestrian features, as indicated by their negative coefficients (-0.149 for young group and -0.300 for old group) from the modeling process, and the influence of the old age group is significant at 90% confidence interval. These results are consistent with the results in Figure 17, where both young drivers and old drivers have lower proportion of compliant behavior at pedestrian features, and older drivers have the lowest proportion of compliant behavior among all the three age groups.
- Pedestrian presence at the intersection where the trip event occurs is identified to play a significant role in predicting driver compliant behavior at intersections. The estimated coefficient for pedestrian presence is 0.892 and is significant at 90% confidence level, suggesting that pedestrian presence could significantly improve driver compliant behavior to pedestrian feature signs. The result is consistent with the findings in Figure 13 that drivers performs better in terms of compliant behavior when pedestrians are present, where the proportion of compliant behavior is 88.1% with pedestrian presence and 78.1% without pedestrian presence.
- High risk drivers based on self-risk-taking evaluation tend to have lower probability of compliant behavior than their counterpart group, which is proved by the negative coefficient equal to -0.280. This result is complete reasonable since high risk drivers tend

to perform aggressive or reckless driving more frequently, including being reluctant to comply with the pedestrian features.

- Some factors are identified in data quantities and statistical analysis but not in GLMM modeling results (i.e. daytime/nighttime, driver distraction level), and some factors otherwise (i.e. driver gender, risk levels). These results from two approaches highlight the mixed effects from combinations of factors on driver compliant behavior, and could serve as complementary evidence to each other to enhance our understandings.

## 6.3. Comparison of Phase 2 Findings with Existing Literatures

Understanding the interactions between drivers and pedestrian features is important for developing effective countermeasures to improve pedestrian safety at signalized intersections. Only a limited number of studies evaluated the effectiveness of pedestrian features. In the Phase 2 study, detailed analyses were conducted by the research team regarding driver demographic and risky/distractive behavior characteristics, and solid conclusions were made based on the analyses of sufficient data for these pedestrian features. The results were compared with existing literature as follows.

### *6.3.1. "STOP HERE ON RED" Sign*

Existing Literature:

- According to the *Manual on Uniform Traffic Control Devices* (MUTCD) (FHWA, 2009), "STOP HERE ON RED" signs are implemented for observance of stop lines.
- There is very limited contemporary research regarding the effectiveness of "STOP HERE ON RED" signs in driver compliance.

CUTR Research Findings and Recommendations:

- Compared to the control sites, the implementation of "STOP HERE ON RED" signs increased driver compliant behavior by 8.2% (from 66.3% to 74.5%).
- Male drivers were more likely to comply than female drivers (79.1% vs. 67.3%). The older drivers (ages 60+) had the highest compliance rate. "High risk" drivers and "high distraction" drivers performed significantly inferior in terms of complying with the "STOP HERE ON RED" sign.
- The research team suggests emphasizing education outreach to female drivers, young drivers, "high risk" drivers, and "high distraction" drivers on "STOP HERE ON RED" compliance.

### *6.3.2. "NO TURN ON RED" Sign*

Existing Literature:

- Huang (2000) found through a treatment-and-control study that “NO TURN ON RED” and “YIELD TO PEDESTRIANS” signs could reduce motorists’ illegal right turns on red. In addition, Zegeer et al. (1986) concluded that “NO TURN ON RED” signs with a red ball were more effective than standard black and white “NO TURN ON RED” signs. Pécheux et al. (2009) discovered that active “NO TURN ON RED” signs are “especially effective in visually cluttered areas where motorists are less likely to see and respond to a static sign.”

CUTR Research Findings and Recommendations:

- “NO TURN ON RED” signs induced the highest percentage of compliant behavior (90.9%) among all the examined feature signs, followed by “TURNING VEHICLES YIELD TO PEDESTRIANS” signs (85.7%).
- Further analyses were conducted regarding the influence of driver demographic and risky/distractive behavior characteristics on driver performance of compliance at feature signs.
- The research team suggests that “NO TURN ON RED” signs are favorable at intersections with high intersecting traffic volumes and pedestrian volumes; a sign with a red ball is recommended.

### *6.3.3. “TURNING VEHICLES YIELD TO PEDESTRIANS” Sign*

Existing Literature:

- According to MUTCD, this sign is used to remind drivers making turns to yield to pedestrians.
- Karkee et al. (2006) tested the effects of “TURNING TRAFFIC MUST YIELD TO PEDESTRIANS” signs and found increases in yield behavior to pedestrians. Pulugurtha et al. (2010) also discovered a general improvement in driver yielding behavior due to installation of “YIELD TO PEDESTRIANS” signs. Pécheux et al. (2009) comprehensively compared the effectiveness of multiple countermeasures to increase pedestrian safety, including Danish offset, high visibility crosswalk, median refuge, advanced yield marking, and “YIELD TO PEDESTRIANS” signs.

CUTR Research Findings and Recommendations:

- Drivers were generally sensitive to pedestrian presence at both feature sites and control sites. The compliance percentages for both groups were higher when pedestrians were present than those when pedestrians were absent.
- Compared with the control sites, the installation of “TURNING VEHICLES YIELD TO PEDESTRIANS” produced a considerable increase of 19% (from 66.7% to 85.7%) in the percentage of driver compliant behavior.

- The research team suggests that “TURNING VEHICLES YIELD TO PEDESTRIANS” signs may be implemented jointly with “RIGHT ON RED ARROW AFTER STOP” signs, high visibility crosswalks, or advance yield markings to enhance pedestrian safety at intersections.

### *6.3.4. “RIGHT ON RED ARROW STOP” Sign*

Existing Literature:

- Preusser et al. (1981) determined that drivers turning right on red increased right-turn crashes from 1.47% to 2.28% of all pedestrian crashes. Zegeer et al. (1986) revealed that in turning right on red, 56.9% of motorists failed to make a full stop before making the turn. They also concluded that 23.4% of violations of turning right on red resulted in conflicts with pedestrians. Compton and Milton (1994) reported that about two-tenths of 1% of all fatal pedestrian and bike crashes resulted from right turns on red.

CUTR Research Findings and Recommendations:

- The results of data analysis indicated that the presence of “RIGHT ON RED ARROW AFTER STOP” signs increased the percentage of driver compliant behavior significantly, from 31.3% to 74.4%, compared to control sites without the sign.
- The percentage of compliant behavior varied across driver demographic characteristics, including age, gender, and education level, but none of these differences was statistically significant.
- A “RIGHT ON RED ARROW AFTER STOP” sign at a signalized intersection is much more effective than intersections without the sign by emphasizing the mandatory stop before turning right on red, and there is a higher probability that drivers observe and yield to pedestrians. Therefore, “RIGHT ON RED ARROW AFTER STOP” signs are recommended to be implemented at eligible locations and should be installed jointly with “TURNING VEHICLES YIELD TO PEDESTRIANS” signs to enhance pedestrian safety. In addition, a possible reason for the low proportion of compliant behavior for female drivers at “RIGHT ON RED ARROW AFTER STOP” might be that female drivers generally have lower eye height and fixation, inducing more limited visibility due to obstruction. Therefore, it is recommended to use overhead “RIGHT ON RED ARROW AFTER STOP” when possible to mitigate the potential visibility issue.

## 7. DEVELOPMENT OF IMPLEMENTABLE COUNTERMEASURES

The Phase 2 research project to date has resulted in the identification of implementable safety improvements that can be effectively put into practice. Based on the early findings of Phase 2, the potential countermeasures anticipated can be divided into three categories—Engineering, Education, and Enforcement—as presented below.

### 7.1. Engineering Countermeasures

- ***Implement "NO TURN ON RED" static or blankout signs when possible*** – A driver compliance rate of 90.9% for "NO TURN ON RED" signs was the highest among all four pedestrian features noted in Phase 2. The research team also found that potentially highly-distracted drivers had higher compliance rates than potentially low-distracted drivers, perhaps because they tend to stop to use their cell phones. Because of the highest compliance rate among the four study features, "NO TURN ON RED" signs are strongly recommended for implementation at signalized intersections when possible. The implementation should consider both static and blankout signs. When traffic volumes on cross streets are low or/and sight distance problems exist due to intersection layout, a "NO TURN ON RED" blankout sign is recommended for implementation at that signalized intersection to avoid unnecessary delay for right-turning traffic. A "NO TURN ON RED" blankout sign is triggered when a pedestrian presses the pedestrian pushbutton to cross a street. The "NO TURN ON RED" blankout sign also can be programmed to turn on during specific periods when the traffic on cross streets is heavy. Examples of "NO TURN ON RED" static and blankout signs are shown on Figure 26.

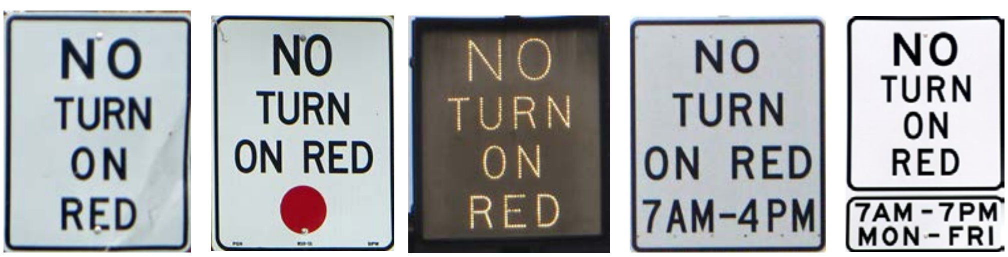



**Figure 26 - Examples of "NO TURN ON RED" static and blankout signs**

- Implement "RIGHT ON RED ARROW AFTER STOP," "RIGHT TURN ON RED AFTER STOP," or "RIGHT ON RED AFTER STOP" signs if "NO TURN ON RED" signs are not implemented – There is a much higher driver compliance rate of 74% at signalized intersections with a "RIGHT ON RED ARROW AFTER STOP" sign than the rate of 31.3% for locations without this feature sign. Therefore, it is strongly recommended to implement "RIGHT ON RED ARROW AFTER STOP" or "RIGHT TURN ON RED AFTER STOP" signs if "NO TURN ON RED" signs will not be implemented. The "RIGHT TURN ON RED AFTER STOP" signs should be implemented at locations with an exclusive right-turn lane but no right-turn red arrow. Examples of "NO TURN ON RED" static and blankout signs are shown in Figure 27.


**Figure 27 - Examples of "RIGHT ON RED ARROW AFTER STOP" and "RIGHT TURN ON RED AFTER STOP" signs**

– ***Implement both "NO TURN ON RED" and "STOP HERE ON RED" signs at the same intersection*** **–** This implementation could greatly increase the driver compliance rate for these pedestrian features and improve pedestrian safety and perception at signalized intersections. Figure 28 shows an example of a "NO TURN ON RED" blankout sign and a "STOP HERE ON RED" sign for the westbound approach at the Lockwood Ridge Road and 17$^{th}$ Street intersection in Sarasota, Florida. Another example is on the westbound approach at the US 41 and Gibsonton Drive intersection in Gibsonton, Florida, as shown in Figure 29.

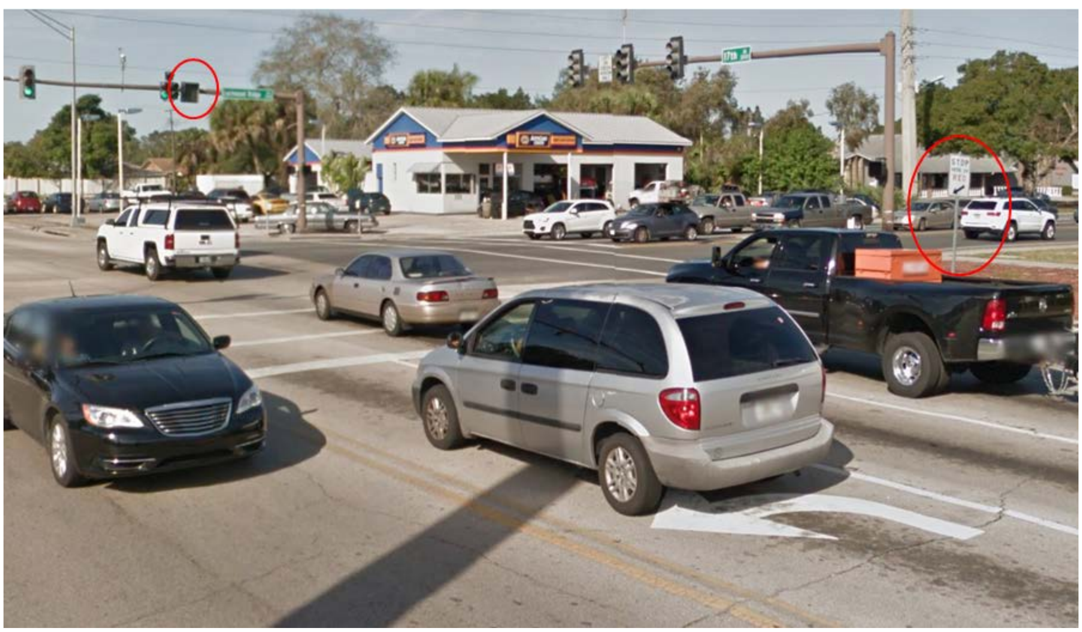


**Figure 28 - Example 1 with both "NO TURN ON RED" and "STOP HERE ON RED" signs**


**Figure 29 - Example 2 with both “NO TURN ON RED” and “STOP HERE ON RED” signs**

– ***Implement “RIGHT ON RED ARROW AFTER STOP” and “TURNING VEHICLES YIELD TO PEDESTRIANS” signs at the same intersection*** **–** A “RIGHT ON RED ARROW AFTER STOP” sign at a signalized intersection is much more effective than turning right on red at an intersection without a sign. A “RIGHT ON RED ARROW AFTER STOP” sign is recommended to be implemented at eligible locations jointly with the installation of “TURNING VEHICLES YIELD TO PEDESTRIANS” signs to enhance pedestrian safety.

– ***Implement overhead signs for “NO TURN ON RED” or” RIGHT ON RED ARROW AFTER STOP” signs when possible*** **–** This study showed that drivers had a compliance rate of 89.9% for overhead signs, which is much higher than the 74.9% compliance rate for roadside signs. The results indicate that drivers are not likely to miss an overhead sign because it is next to the traffic signal heads. A driver may miss a roadside sign installed upstream of a stop bar or when stopped at an intersection. Therefore, overhead signs are recommended, especially for “NO TURN ON RED” or” RIGHT ON RED ARROW AFTER STOP” signs. A comparison of overhead and roadside “NO TURN ON RED” signs for the northbound W Platt Street and S Howard Avenue intersection in Tampa is shown in Figure 30. In Figure 30(a), both the overhead sign and roadside sign are visible to a driver. In Figure 30(b), if a driver just looks straight ahead, he or she can see the overhead sign but not the roadside sign.


(a) View of both roadside and overhead signs (b) View of overhead sign only

**Figure 30 - Comparison of overhead sign and roadside sign**

- ***Implement "STOP HERE ON RED" signs at locations with frequent non-compliance* –** There is a higher driver compliance rate at signalized intersections with a "STOP HERE ON RED" sign than those without the sign. It is highly recommended to implement "STOP HERE ON RED" signs at locations with frequent non-compliance. Their implementation can provide adequate space between vehicles and pedestrians crossing streets, offer better visibility for drivers to see pedestrians crossing streets, encourage pedestrians to cross streets at signalized intersections, and improve pedestrian safety at signalized intersections.
- ***Implement at least one pedestrian feature sign* –** It was found that driver compliance rates were statistically significantly higher for locations with pedestrian feature signs than locations without signs. It is recommended at least one pedestrian feature sign be installed at signalized intersections, especially a "NO TURN ON RED" sign, either static or blankout, depending on traffic conditions, or a "RIGHT ON RED ARROW AFTER STOP" sign at a eligible location.

## 7.2. Education Countermeasures

- ***Conduct educational outreach to female drivers to improve their compliance rate for "STOP HERE ON RED" signs***: Female drivers tend to be more distracted than male drivers and have a much lower compliance rate for "STOP HERE ON RED" signs than that of male drivers. Education efforts should focus on female drivers to improve their compliance rate for "STOP HERE ON RED" signs.
- ***Conduct educational outreach to young drivers to improve their compliance rate for "STOP HERE ON RED" signs***: Young drivers ages 16–24 exhibit riskier behaviors than

drivers in other age groups and have a statistically lower compliance rates for “STOP HERE ON RED” signs than drivers in other age groups. Education efforts should focus on young drivers to improve their compliance rate for “STOP HERE ON RED” signs.

– ***Conduct educational outreach to male drivers to improve their compliance rate for “NO TURN ON RED signs***: Male drivers have a statistically lower compliance rate for “NO TURN ON RED” signs than female drivers. Education efforts should focus on male drivers to improve their compliance rate for “NO TURN ON RED” signs.

– Conduct educational outreach to older drivers to improve their compliance rate for “NO TURN ON RED” and “RIGHT ON RED ARROW AFTER STOP” signs: Drivers ages 60 or older have a statistically lower compliance rate for “NO TURN ON RED” signs than drivers in other age groups. This age group has a low compliance rate (69.6%) for “RIGHT ON RED ARROW AFTER STOP” signs. Education effort should focus on drivers ages 60 or older to improve their compliance rate for “NO TURN ON RED” sign and “RIGHT ON RED ARROW AFTER STOP” signs.

– ***Conduct educational outreach to reduce risky or/and distracted behaviors while driving, especially for young drivers***: Based on the self-reported survey responses, about 34% of drivers in age group 16–24 and 35% in age group of 25–59 are frequently distracted. About 37% of female drivers often perform secondary tasks while driving. Nearly 25% of young drivers exhibit more risky driving behaviors. Distracted drivers and/or risky drivers generally have lower compliance rates for pedestrian features, so education efforts should also focus on them.

### 7.3. Enforcement Countermeasures

– Conduct three-stage high visibility enforcement to improve the compliance rates for “STOP HERE ON RED” signs and “RIGHT ON RED ARROW AFTER STOP” or “RIGHT ON RED AFTER STOP” signs: Among the four features studied, compliance rates for “STOP HERE ON RED” and “RIGHT ON RED ARROW AFTER STOP” signs were about 75%, which is much lower than the compliance rate for “NO TURN ON RED” signs. Three-stage enforcement efforts including education, warnings, and citations are recommended for these two pedestrian features.

For site selection for a future pilot implementation, the research team will establish eligibility criteria and guidelines in the first project task. The implementation of pedestrian features is to increase pedestrian safety, but when implemented improperly or at wrong locations, they might cause unnecessary vehicle delay or/and increase driver non-compliance. Therefore, proper site selection for the pilot implementation is important. The research team will develop criteria and guidelines for site selection using crash history, vehicle and pedestrian volumes, and pedestrian crash type information provided by a dataset created for FDOT in a current project. Also, coordination and input from FDOT District offices will be required to ensure local knowledge inclusion.

### 7.4. Implementation Phase Envisioned

The proposed pilot implementation project would implement and evaluate selected countermeasures recommended from Phase 2 via pilot studies in the northern, central, and southern regions of Florida, as shown in Figure 31, to support future statewide implementations. Based on guidance from FDOT, the pilot implementation project will finalize the recommended countermeasures from Phase 2 and implement them at selected sites in Florida. The evaluation results and research findings from the pilot project will provide FDOT with essential experience and knowledge to successfully implement the countermeasures in the future statewide implementations.


**Figure 31 - Regions for pilot implementations of selected pedestrian features**

### 7.5. Involvement of Implementation of Research Results for Pilot Implementations

The major goal of a future pilot project is to conduct pilot studies to deploy recommended countermeasures from the Phase 2 project in selected areas in Florida, evaluate the effectiveness of these countermeasures via before-and after studies and detailed data analysis, and recommend final countermeasures for future statewide implementation to improve pedestrian safety at signalized intersections. To achieve the major goal of the pilot implementation project, the following supporting project tasks are proposed:

Task 1: Finalization of Pilot Study Sites and Countermeasures
Task 2: Deployment of Selected Countermeasures
Task 3: Data Collection and Compilation
Task 4: Data Analysis and Evaluation of Deployed Countermeasures
Task 5: Research Findings and Final Recommendations for Statewide Implementations
Task 6: Production of Draft Report and Closeout Teleconference
Task 7: Production of Final Report

### 7.6. Efforts for Full Implementation beyond Pilot Implementations

Pedestrian safety is one of the highest priorities in Florida. FDOT is committed to implementing effective countermeasures to improve pedestrian safety and make Florida a pedestrian-friendly state. The agency is very supportive of this research project and will share part of the cost for the Phase 3 project if awarded. FDOT plans to develop a future statewide implementation plan to implement the final selected countermeasures beyond the pilot/demo effort. The statewide implementation will be led by the FDOT Central Office and District offices via the FDOT Work Program and will be implemented step-by-step starting with signalized intersections with pedestrian safety problems and compliance issues.

In the proposed pilot implementation project, it is the intention of the research team to develop guidelines for FDOT related to where the recommended engineering countermeasures should be implemented and to further fine-tune the guidelines based on the experience and findings obtained from the pilot project. The final guidelines for site selection can be used as guidance to shape policies and procedures at the FDOT Central Office and District levels for full implementation of these pedestrian features, with the goal of increasing pedestrian safety and reduce pedestrian crashes, injuries, and fatalities.

### 7.7. Anticipated Benefits

The anticipated benefits of this implementation will be improved driver compliance with pedestrian features at signalized intersections and increase awareness of pedestrian safety issues and traffic laws pertaining to pedestrians. Higher compliance rates with pedestrian feature signage, signals, and pavement markings will result in fewer conflicts between vehicles and pedestrians at signalized intersections, which could significantly improve pedestrian safety. As a result, it is expected that lower crash rates will occur at the locations at which the pilots will be implemented. Therefore, continuing the research can achieve a result that FDOT and Florida local transportation agencies can implement and use to reduce the number of pedestrian crashes at signalized intersections.

Efforts to revise existing devices or approve new devices will be minimal since implementation of recommended countermeasures will not include development of new control devices; existing signs will be installed at problem locations. Also, FDOT has ongoing efforts to increase traffic law awareness through education campaigns, and new education activities can be included in those efforts. It is expected that statewide implementation of the final countermeasures will significantly improve pedestrian safety and pedestrian perception at signalized intersections and reduce pedestrian-related fatalities, crashes, and injuries at signalized intersections in Florida.

# 8. CONCLUSIONS AND RECOMMENDATIONS

This research has successfully used NDS and RID data to investigate and analyze the interactions between drivers and pedestrian features, develop implementable countermeasures in engineering, education, and enforcement, and reach solid conclusions and recommendations. The results and findings of this project provide a clear insight of driver compliance rates with four main pedestrian feature signs at signalized intersections, and full support for recommended countermeasures for implementation to improve pedestrian safety at signalized intersections.

## 8.1. Conclusions

The conclusions of this Phase 2 project are provided in two categories, one based on the comprehensive quantitative and statistical data analysis and the other on development of implementable countermeasures.

### *8.1.1. Results and Findings*

- Among four study pedestrian features, “NO TURN ON RED” signs had the highest driver compliance rate of 90.9%, followed by “TURNING VEHICLES YIELD TO PEDESTRIANS” at 85.7%, “STOP HERE ON RED” at 74.5% and “RIGHT ON RED ARROW AFTER STOP” at 74.4%. Limited pedestrian presence was observed for the “TURNING VEHICLES YIELD TO PEDESTRIANS” sign.
- From the comparison between the feature and control groups, the overall proportion of driver compliant behaviors to the feature intention was higher at the feature sites than that at the control sites (without the features signs), and the difference was statistically significant at a 95% confidence level.
- From the comparison of driver compliant behaviors by gender at feature sites, for the “STOP HERE ON RED” and “RIGHT ON RED ARROW AFTER STOP” features, female drivers were less likely to comply than male drivers and the differences were statistically significant. For the “NO TURN ON RED” feature, female drivers were more likely to comply with the feature than male drivers and the difference was also statistically significant.
- From the comparison of driver compliant behaviors by age at feature sites, the mid-age drivers (ages 25–59) had the highest compliance rate of 93.8% for “NO TURN ON RED,” 100% for “TURNING VEHICLES YIELD TO PEDESTRIANS,” and 77.5% for “RIGHT ON RED ARROW AFTER STOP.”
- From the comparison of driver compliant behaviors by age at feature sites, older drivers (ages 60+) had the lowest compliance rate of 76.4% for “NO TURN ON RED” and 69.6% for “RIGHT ON RED ARROW AFTER STOP.” Older drivers (ages 60+) had the highest compliance rate of 79.6% for “STOP HERE ON RED.” Younger drivers had the

lowest compliance rate of 71.1% for “STOP HERE ON RED” and 75.0% for “TURNING VEHICLES YIELD TO PEDESTRIANS.”

– From the comparison of compliant behaviors by education level at feature sites, overall, a higher education level led to a higher proportion of driver compliant behaviors at sites with pedestrian features.

– From the comparison of compliant behaviors by ADHD level at feature sites, drivers without possible ADHD symptoms had a higher proportion of compliance than their counterpart groups.

– From the comparison of compliant behaviors by sign locations at feature sites, overhead signs on signal mast arms or span wires produced the higher proportion of compliant behaviors than that of right side (roadside); the compliance rate was statistically significant at the 95% significance level.

– For impacts of pedestrian presence, drivers were generally sensitive to pedestrian presence at both feature and control sites and likely to yield pedestrians. Drivers showed a much higher proportion of compliance at the feature sites than at the control sites (78.1% vs. 64.3%) when pedestrians were not present, indicating that drivers most likely will comply with pedestrian features at feature sites even though there are no pedestrians present or drivers do not see them.

– From the consistency of driver compliance performance perspective, male drivers demonstrated comparable proportions of compliant behaviors with pedestrian feature signs among age groups. Female drivers showed a larger variation for proportions of compliant behaviors among age groups. Younger (ages 16–24) female drivers exhibited the lowest proportion of compliant behaviors, with only 73.3% overall compliance.

– From the results of self-evaluation on risk levels and distraction levels, more female drivers were classified into the groups of “High Risk” and “High Distraction” than male drivers. Younger drivers (ages 16–24) took significantly more risks than those in other age groups. Younger drivers (ages 16–24) and mid-age drivers (ages 25–59) were more likely to be distracted than older drivers (ages 60+). Older drivers (ages 60+) took significantly fewer risks and were less likely to be distracted than other drivers.

– From the perspective of impacts of driver risk and distraction characteristics on compliant behaviors:

  - At sites with a “STOP HERE ON RED” sign, drivers in the “Low Risk” or “Low Distraction” groups were more likely to comply with the sign than were those in the corresponding counterpart group.
  - At sites with a “NO TURN ON RED” sign, drivers in the “High Risk” and “Low Risk” groups produced comparable proportions of compliance. Drivers in the “High Distraction” group were more likely to comply with the sign than drivers in the “Low

Distraction" group; the difference in terms of proportion of compliance was statistically significant at a 95% confidence level. This is reasonable because highly-distracted drivers are more likely to become involved in secondary tasks, such as checking their cell phones, eating, etc., and they are more likely to stop at this feature sign to perform these activities while ensuring driving safety at the same time.

- At sites with a "TURNING VEHICLES YIELD TO PEDESTRIANS" sign, drivers in the "Low Risk" or "Low Distraction" groups were more likely to comply with the sign than those in the corresponding counterpart group.
- At sites with a "RIGHT TURN ON RED ARROW AFTER STOP" sign, drivers in the "Low Risk" group were more likely to comply with the sign than those in the "High Risk" group, but the difference was not significant. Drivers in the "Low Distraction" group were more likely to comply with the sign than those in the "High Distraction" group; the difference in terms of proportion of compliance was statistically significant at a 90% confidence level.

### *8.1.2. Development of Implementable Countermeasures*

**Engineering**

– Implement "NO TURN ON RED" static or blankout signs when possible.

– Implement "RIGHT ON RED ARROW AFTER STOP," "RIGHT TURN ON RED AFTER STOP," or "RIGHT ON RED AFTER STOP" signs if "NO TURN ON RED" signs are not implemented.

– Implement both "NO TURN ON RED" and "STOP HERE ON RED" signs at the same intersection.

– Implement "RIGHT ON RED ARROW AFTER STOP" and "TURNING VEHICLES YIELD TO PEDESTRIANS" signs at the same intersection.

– Implement overhead signs for "NO TURN ON RED" or" RIGHT ON RED ARROW AFTER STOP" signs when possible.

– Implement "STOP HERE ON RED" signs at locations with frequent non-compliance.

– Implement at least one pedestrian feature sign

**Education**

– Conduct educational outreach to female drivers to improve their compliance rate for "STOP HERE ON RED" signs.

– Conduct educational outreach to young drivers to improve their compliance rate for "STOP HERE ON RED" signs.

– Conduct educational outreach to male drivers to improve their compliance rate for "NO TURN ON RED" signs.

- Conduct educational outreach to older drivers to improve their compliance rate for "NO TURN ON RED" and "RIGHT ON RED ARROW AFTER STOP" signs.
- Conduct educational outreach to reduce risky or/and distracted behaviors while driving, especially for young drivers.

**Enforcement**

- Conduct three-stage High Visibility Enforcement to improve compliance rates for "STOP HERE ON RED," "RIGHT ON RED ARROW AFTER STOP," and "RIGHT ON RED AFTER STOP" signs.

## 8.2. Recommendations

The ultimate goals for this research were to transform from concept to countermeasures and from research to deployment of implementable countermeasures to improve pedestrian safety at signalized intersections in Florida and the nation. The major recommendations from this Phase 2 project are to implement recommended countermeasures via pilot studies, fine-tune the countermeasures based on the results of the pilot implementations, develop a future statewide implementation plan, and implement the finalized countermeasures statewide to improve pedestrian safety and reduce pedestrian related fatalities, injuries and crashes in Florida. The specific recommendations include the following:

- Select recommended countermeasures from this research project for pilot implementations at selected signalized intersections in northern, central and southern regions of Florida, and evaluate the implementation results via before-and-after studies.
- Develop criteria and guidelines for site selection for the pilot implementations using crash history, vehicle and pedestrian volumes, and pedestrian crash type information, and also coordinate and obtain inputs from FDOT District offices to ensure local knowledge inclusion.
- Document process, benefits, challenges and solutions of pilot implementations to benefit future statewide implementations.
- Enhance and finalize the countermeasures and implementation guidelines based on the results of the pilot implementations.
- Recommend FDOT Central Office and District offices to lead future statewide implementations after the pilot implementations starting with signalized intersections with pedestrian safety problems and compliance issues.

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## APPENDIX A - IRB Protocol

**Title: Understanding Interactions between Drivers and Pedestrian Features at Signalized Intersections-Phase 2**

**PI: Pei-Sung Lin**

**Co-PI: Achilleas Kourtellis**

**IRB Protocol**

### Rationale and Background

One of Florida's highest priorities is investigating major contributing causes for pedestrian fatalities and developing effective countermeasures to significantly improve pedestrian safety in the state. Statistics show that pedestrian crashes tend to be more concentrated at intersections. In Florida, about 31% of pedestrian fatal crashes and about 47% of pedestrian crashes occur at signalized intersections (FIU, 2013). At present, the Florida Department of Transportation (FDOT) and local traffic agencies do not have a clear understanding of the effectiveness of pedestrian features such as pedestrian signs, pedestrian signals, traffic signals, crosswalks, and pavement markings at signalized intersections, with and without the presence of pedestrians. They also do not know the population and demographics on which to focus for educational outreach and law enforcement that will result in significant improvement of their compliance with pedestrian features at signalized intersections. The Strategic Highway Research Program 2 (SHRP2) Naturalistic Driving Study (NDS) recorded the driving behavior of a large sample of drivers in their personal vehicles, offering researchers comprehensive naturalistic driving behavioral data to investigate the interactions between drivers and various pedestrian features at selected signalized intersections through which they drove. The ultimate goal of this research project is to use SHRP2 NDS and roadway information database (RID) datasets to better understand the interaction between drivers and pedestrian features at signalized intersections and to develop effective countermeasures to significantly increase pedestrian safety.

### Existing Research

From the Phase 1 project, the initial research results and preliminary findings offer valuable insight into the effectiveness of specific pedestrian features and the effect of driver characteristics on compliance with individual pedestrian features. The research team also demonstrated the capability to effectively work with the NDS and RID databases. A small sample size was used in Phase 1 to examine selected pedestrian features at signalized intersections, calibrate proposed methodologies for data analyses, and develop and test the Automatic Video Processing Tool and the Data Reduction and Analysis Tool. A larger sample size is needed in Phase 2 so researchers can conduct detailed qualitative and quantitative analyses to obtain a better understanding on the effectiveness of selected pedestrian features at signalized intersections and the effect of driver characteristics on compliance with individual pedestrian features.

**Research Objectives, Questions, and Purpose**

The research team proposes to proceed in Phase 2 based on the foundation built in Phase 1 to finalize the research project and answer the study research question in detail: "How do drivers interact with pedestrian features at signalized intersections when pedestrians are or are not present?" The pedestrian features for this research project include the following pedestrian safety related signs and signals: (1) "Stop Here on Red," (2) "No Turn on Red," (3) "Turning Vehicles Yield to Pedestrians," (4) "Right on Red Arrow after Stop" and "Photo Enforced," and (5) "Permitted Left Turn Signals." Driver interactions with pedestrian features include driver speeds, braking patterns, yielding behaviors, and attention and/or distraction. The Phase 1 project successfully demonstrated the success of the proof-of-concept for the development of countermeasures. The Phase 2 project will complete the research and develop effective and implementable countermeasures that can lead to significant improvement in pedestrian safety at signalized intersections.

The proposed Phase 2 research will continue to align with the American Association of State Highway and Transportation Officials (AASHTO) Safety Task Force's focus areas: (1) driver speed, (2) roadway features and driver performance, (3) preceding contributory events, (4) vulnerable road users, and (5) intersections.

Based on the success and lessons learned from Phase 1, the research team will modify and enhance the research plan, NDS data request, analysis methodologies, and research tools developed in Phase 1 to successfully complete the research project in Phase 2 on (1) interactions between drivers and pedestrian features at signalized intersections and (2) driver characteristics, behaviors, and performance with respect to studied pedestrian features. Based on the Phase 1 experience, the potential outcomes of the research in Phase 2 include the following:

1. Better understanding and detailed findings of the effectiveness of studied pedestrian features at signalized intersections with and without the presence of pedestrians.
2. Better understanding and detailed findings of driver behaviors and compliance with studied pedestrian features at signalized intersection with respect to age, gender, and driving attitudes.
3. Enhancement of research tools developed in Phase 1 to extract and analyze NDS data and recorded videos at signalized intersections to detect the presence of pedestrians, identify traffic signal indications, and organize NDS data for detailed analysis.
4. Development of implementable countermeasures based on the effectiveness of studied pedestrian features and the impact of driver characteristics and demographics on compliance with the intention of the pedestrian features.

**Project Objectives**

The main objectives of the Phase 2 project are to:

1. Fully investigate and better understand the interactions between drivers and pedestrian features at signalized intersections.
2. Produce tangible outcomes and detailed findings.
3. Recommend implementable countermeasures in engineering, education, and enforcement regarding pedestrian features at signalized intersections to improve pedestrian safety in Florida and other states with similar problems.

**Questions**

These research questions are to be answered with the data acquired during the study. Specific questions are:

1. What are the driver interactions with different pedestrian features at signalized intersections?
2. What is the effectiveness of a specific pedestrian feature?
3. What are specific interactions between drivers and pedestrians?
4. Will drivers interact with pedestrian features differently when pedestrians are present?
5. What are the impacts of driver characteristics such as gender and age group on driver interactions?
6. What are the impacts of driver attention and/or distraction on driver interactions?

**Study Design**

The data were collected during the SHRP2 NDS (USF IRB#Pro00001238). The data are housed and shared by Virginia Tech Transportation Institute (VTTI) with a Data Sharing Agreement contract. The participants of the SHRP2 NDS study were healthy adults and minors from ages 16 and up, having an eligible vehicles and residing in the study areas defined as counties of interest. The study had total of 6 sites at the following locations:

– Tampa Bay, FL
– Buffalo, NY
– State College, PA
– Bloomington, IN
– Durham, NC
– Seattle, WA

For the current study, VTTI will provide datasets related to traversals of SHRP2 NDS participants through intersections in the Tampa Bay Area only as specified by the CUTR research team. When this list of intersections is provided to VTTI, it will provide the number of trips, traversals, and participants traversing those intersections. The CUTR research team will then make a final selection of intersections based on the data available.

The data needed to conduct the Phase 2 project come from the same datasets as in Phase 1. The major difference is the amount of data needed for a large sample for statistical analysis on the effectiveness of pedestrian features and comprehensive analysis on the impact of driver characteristics and behaviors on compliance with pedestrian features. A large sample size with pedestrian presence also is needed. This was an issue with Phase 1 data – pedestrian presence was found in only 7.5% of the requested short videos. In addition, not all pedestrian presence warrants attention from a driver; only pedestrians close to a crosswalk or actively crossing are of concern. This area can be a larger focus in Phase 2 so that a detailed analysis can be performed and comprehensive results obtained. In addition to increased pedestrian presence, a larger number of videos can provide a larger sample of drivers arriving at an intersection when the signal is red instead of green, since the studied features apply primarily to red signal indication. Because the traffic signal indication is not available in the NDS dataset, videos of only red signal activity cannot be requested. With the use of the video detection tool developed in Phase 1 by the research team, more videos can be scanned to flag the change of signal, thereby providing a sample that will show red signal indications when drivers arrive at an intersection. The research team may acquire data as needed from one of five sites to supplement Tampa Bay site data.

During Phase 1, 2,700 videos were requested and provided by VTTI, but 16% were not usable for several reasons: the video was obstructed by an object on the vehicle's windshield, the video resolution was so low that features could not be determined, the video was blurred (out of focus), there was no video (file was blank), and the video segment provided started in the wrong place since the main interest was when a driver was passing through an intersection. With a larger sample size and adequate funding, the researchers can scrap these videos and request more to account for this occurrence. This could not be accomplished in Phase 1 due to limited funds and time.

In Phase 2, the number of video segments for each feature site will be doubled by either adding more intersections or requesting more traversals per intersection. This will ensure adequate data for analysis. Also, the number of full trips will be doubled to allow for more information per participant to observe driving behaviors at multiple intersections. This number also will account for the unusable videos and videos of green time through an intersection (red time is preferred).

Personally Identifiable Information (PII) data will not be used in Phase 2.

## Expected Results

The quantitative methods including statistical analysis will be applied to compare the impacts of different pedestrian features on driving behaviors with or without the presence of pedestrians. The effectiveness of specific pedestrian features on driving behaviors will be evaluated. For data that include interactions between drivers and pedestrians, further analysis will be performed to understand how the pedestrian features at signalized intersections affect driver yield behaviors to pedestrians. The impact of driver characteristics on driver interaction with pedestrian features also will be examined.

The initial data analysis in the Phase 1 project will help answer the major research question: How do drivers interact with pedestrian features at signalized intersections when pedestrians are or are not present? Specifically, the initial data analysis in Phase 1 intends to provide the initial answers to the following specific research questions:

1) What are the driver interactions with different pedestrian features at signalized intersections?
2) What is the effectiveness of a specific pedestrian feature?
3) What are specific interactions between drivers and pedestrians?
4) Will drivers interact with pedestrian features differently when pedestrians are present?
5) What are the impacts of driver characteristics such as gender and age group on driver interactions?
6) What are the impacts of driver attention and/or distraction on driver interactions?

The aim is to produce findings based on driver-infrastructure interaction and driver-pedestrian interaction.

## Name of the Principal Investigator

The PI is Pei-Sung Lin, Ph.D., P.E., PTOE, FITE, Program Director of the ITS, Traffic Operations and Safety Program at the Center for Urban Transportation Research (CUTR) at USF.

## Potential Risks to the Subjects

No risk is associated with analysis of this data. The data were collected and are stored with the highest importance on security and confidentiality. No identifiable information will be shared with the research team unless an additional agreement is in place to access the driver video which includes the driver’s face. This can only occur if present at VTTI secure data enclave and no data will leave the site.

## Potential benefits to the Subjects

No identified benefits to the subjects are available.

General information about the NDS can be found at [www.drivingstudy.org](http://www.drivingstudy.org).

## APPENDIX B - IRB Approval Letter

UNIVERSITY OF SOUTH FLORIDA

RESEARCH INTEGRITY AND COMPLIANCE
Institutional Review Boards, FWA No. 00001669
12901 Bruce B. Downs Blvd., MDC035 • Tampa, FL 33612-4799
(813) 974-5638 • FAX (813) 974-7091

March 23, 2016

Pei-Sung Lin, Ph.D., P.E., PTOE
CUTR - Center for Urban Transportation Research
4202 E. Fowler Ave, CUT 100
Tampa, FL 33620

RE: Not Human Subjects Research Determination

IRB#: Pro00025890

Title: Understanding Interactions between Drivers and Pedestrian Features at Signalized Intersections-Phase 2

Dear Dr. Lin:

The Institutional Review Board (IRB) has reviewed your application and determined the activities do not meet the definition of human subjects research. Therefore, this project is not under the purview of the USF IRB and approval is not required. If the scope of your project changes in the future, please contact the IRB for further guidance.

All research activities, regardless of the level of IRB oversight, must be conducted in a manner that is consistent with the ethical principles of your profession. Please note that there may be requirements under the HIPAA Privacy Rule that apply to the information/data you will utilize. For further information, please contact a HIPAA Program administrator at 813-974-5638.

We appreciate your dedication to the ethical conduct of research at the University of South Florida. If you have any questions regarding this matter, please call 813-974-5638.

Sincerely,

John A Schinka, Ph.D.

John Schinka, Ph.D., Chairperson
USF Institutional Review Board