Safety Evaluation of Alternatives for Installing Pedestrian Signals Under Side Street Green Operation

Prepared by:
John N. Ivan, PhD, PE, Kai Wang, PhD, Marisa Auguste, Olin Green

Report Number:
CT-2321-F-23-1

Final Report

June 14, 2023

Research Project:
SPR-2321

Name of the performing organization
University of Connecticut
School of Engineering
Connecticut Transportation Institute

Submitted to:
Connecticut Department of Transportation
Bureau of Policy and Planning
Research Section

David C. Elder
Transportation Assistant Planning Director

TECHNICAL REPORT DOCUMENTATION PAGE

1. Report No. CT-2321-F-23-1	2. Government Accession No.	3. Recipients Catalog No.

4. Title and Subtitle Safety Evaluation of Alternatives for Installing Pedestrian Signals Under Side Street Green Operation	5. Report Date June 14, 2023
	6. Performing Organization Code
7. Author(s) John N. Ivan, Kai Wang, Marisa Auguste, and Olin Green	8. Performing Organization Report No.
9. Performing Organization Name and Address University of Connecticut, Connecticut Transportation Institute 270 Middle Turnpike, Unit 5202 Storrs, CT 06269-5202	10. Work Unit No. (TRIS)
	11. Contract or Grant No. CT Study Number SPR-2321
	13. Type of Report and Period Covered FINAL REPORT 05/01/2021-06/30/2023
12. Sponsoring Agency Name and Address Connecticut Department of Transportation 2800 Berlin Turnpike Newington, CT 06131-7546	14. Sponsoring Agency Code SPR-2321

15. Supplementary Notes
A study conducted in cooperation with the U.S. Department of Transportation and Federal Highway Administration

16. Abstract
The objective of this project was to carry out a safety evaluation of conversion of intersections owned by CTDOT operating under side street green pedestrian phasing to concurrent pedestrian phasing. Side street green phasing means that pedestrians cross the main road during the minor road green phase, and there is no special pedestrian phasing or signal faces. With concurrent phasing, pedestrians continue to cross the major road during the minor road phase, but they are given "Walk" and "Don't Walk" indications. The safety evaluation included observation of and analysis of differences in the distribution of pedestrian-vehicle interaction, severity, and compliance of pedestrians with signal operation for both treatment and control intersections. Intersections operating under side street green signal operation were formed into cohort groups with similar characteristics such as crossing distance, traffic volume, and types of pedestrian amenities. An intersection with similar characteristics operating under exclusive pedestrian phasing, in which pedestrians are provided with their own phase during which all motorized traffic is stopped, was added to each cohort group for comparison. During a before period, interactions between pedestrians and vehicles were observed at all intersections, along with how long each pedestrian waited before crossing the road and how long it took the pedestrian to cross the road. Between the before and after periods, one or two side street green intersections in each cohort group were converted to concurrent phasing, half with auxiliary signage alerting pedestrians and motorists that motorists and pedestrians would travel during the same phase and that motorists should yield to pedestrians. After the conversion was complete, the same observations were made again in an after period at all study locations. Weighted binary regression was used to predict the probability of any given pedestrian experiencing a conflict with a motor vehicle, defined according to the Swedish Conflict Technique. Intersections operating with either concurrent or exclusive phasing reduce the probability of a conflict almost 50% compared to side street green intersections. Binary regression was also used to predict the probability of a pedestrian being compliant with the signal operation. Intersections with concurrent operation with auxiliary signage showed almost 50% higher compliance compared with concurrent operation without auxiliary signage and exclusive phase intersections. The findings suggest that it would be beneficial to convert intersections with side street green or exclusive phase operation to concurrent phasing, but that the auxiliary signage is helpful to ensure pedestrian compliance.

17. Key Words	18. Distribution Statement No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA. 22161

19. Security Classif. (Of this report) Unclassified	20. Security Classif.(Of this page) Unclassified	21. No. of Pages 51	22. Price N/A

DISCLAIMER

The contents of this report reflect the views of the authors, who are responsible for the facts and accuracy of the data presented herein. The contents do not reflect the official views or policies of the State or the Federal Highway Administration. This report does not constitute a standard, specification or regulation.

ACKNOWLEDGEMENTS

The authors would like to acknowledge Connecticut Department of Transportation Maintenance Districts 1, 3, and 4 for installing the new pedestrian signal heads and signage at the selected locations.

METRIC CONVERSION FACTORS

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

EXECUTIVE SUMMARY

This report describes research investigating the safety effects of converting the pedestrian signal operation at several intersections in Connecticut from side street green to concurrent phasing. "Side Street Green" means that pedestrians cross the main road during the minor road green phase. There is no special pedestrian phasing, though a push button is provided to extend the green time long enough for pedestrians to cross the major road. With concurrent phasing, pedestrians continue to cross the major road during the minor road green phase, but they are given "Walk" and "Don't Walk" indications (expressed as icons) in conjunction with countdown timers. The motivation for CTDOT to consider this new signal operation is to provide better consistency in communication to pedestrians and motorists about what to expect from the signal operation and when pedestrians should and should not be crossing the road while avoiding misleading pedestrians into believing they do not need to interact with motor vehicles while crossing the road.

First, the research team obtained a list of signalized intersections maintained by the Connecticut Department of Transportation (CTDOT) that were operating under side street green operation and, thus, candidates for conversion. The research team then selected from this list groups of intersections with similar characteristics, such as crossing width, the number of vehicle lanes, AADT, and the presence of pedestrian infrastructure. To each group was added an intersection with similar characteristics operating under exclusive phasing, in which pedestrians are provided with their own phase during which all motorized traffic is stopped. Data related to individual pedestrian crossing experiences, the type of pedestrian-vehicle interaction, vehicular volumes, and signal compliance were collected at the selected intersections in the before period. Observations were made between noon and 9 PM for periods of between four and six hours, varying by intersection due to weather conditions and observer availability. All observers were trained in the Swedish Traffic Conflict Technique and multiple tests were conducted to ensure consistency among all the observers.

After data collection concluded for the before period, two cohort groups of sites were excluded from the project due to an insufficient number of pedestrian observations. Next, two of the three side street green intersections in each group were designated for conversion to concurrent phasing; one intersection would be converted to concurrent phasing with auxiliary signage, while the other would be converted to concurrent phasing without auxiliary signage. Physical installation of each treatment began in April 2022 and ended in September of the same year. Due to issues that arose during this timeframe, only 10 of the original 16 intersections were converted to concurrent phasing; as a result, a third cohort group of intersections was removed from the project and the study design was adjusted to accommodate this change. Subsequently, data were collected at the remaining 28 intersections in the after period following the same guidelines as the before data. No changes in physical intersection characteristics were noted except for the conversion from side street green to concurrent pedestrian signal phasing at each treatment site.

Since each pedestrian observation was classified based on whether a conflict occurred, two different binary logistic regression models were used to predict the probability of a conflict for each pedestrian that crossed the road. Model 1 was an unmodified logit model and Model 2 used weights in a binary logit framework to account for the imbalance of conflict and non-conflict events that was present in the dataset. Although Model 1 was unable to predict any pedestrian-vehicle conflicts, its coefficient estimates were similar to those in Model 2. The statistically significant covariates in Model 2 are waiting time, crossing time, median presence, log of observed vehicle volume, observation in August or November, and a binary variable that indicates if an intersection had either concurrent or exclusive phasing.

It is noted that in the after period, no pedestrian vehicle conflicts were recorded at any of the intersections with the new concurrent phasing. In addition to this, intersections with either concurrent or exclusive phasing, compared to sites with side street green phasing, were found to decrease the odds of a conflict by over 48%. Other variables that were found to reduce the probability of a conflict were a pedestrian’s waiting time, the presence of a median, observations gathered in August, and observations collected in November, which decreased the odds of a conflict by 0.9%, 88.3%, 58.0%, and 91.4%, respectively. A unit increase in the crossing time of a pedestrian and the natural log of the observed vehicle volume were found to increase the odds of a conflict by 11.3% and 3000.2%, respectively.

Binary logistic regression was also used to estimate the probability of pedestrian compliance with the traffic signal indications for each person that crossed the street. In this case, weights were not needed to potentially improve the model because there was a relatively even number of compliant and noncompliant pedestrian crossings. In this model, the significant covariates are waiting time, concurrent phasing without signage, exclusive phasing, crossing distance, and the presence of crosswalks. To demonstrate the effects of each type of pedestrian signal on pedestrian compliance, *k*-means clustering was used to create six prototypical intersections based on the data that were gathered in this study. Using the characteristics of these example intersections and the coefficient estimates from the pedestrian compliance model, the probability of compliance was predicted four times for each intersection, such that each intersection was treated as if it operated under one of the four types of pedestrian signal phasing.

Intersections with exclusive phasing or concurrent phasing without signage, compared to side street green signal operations, were found to decrease the odds of pedestrian compliance by 45.3% and 45.7%, respectively. Unit increases in the time a pedestrian spent waiting and the crossing width, as well as the presence of painted crosswalks, were found to increase the odds of pedestrian compliance by 2.7%, 8.6%, and 103.7%, respectively. Based on characteristics of the six prototypical intersections, side street green and concurrent phasing with signage were also found to have significantly higher rates of pedestrian compliance than either exclusive or concurrent phasing without signage. The results of this analysis suggest that auxiliary signage is needed to increase pedestrian compliance at concurrent phase intersections; if this feature is not present, concurrent phasing appears to have a decreased probability of compliance compared to the previous side street green signal operations.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1 INTRODUCTION

1.1 Project Motivation and Background

The Connecticut Department of Transportation (CTDOT) has many traffic signals operating with the pedestrian phasing scheme known as “Side Street Green”. This phasing scheme allows for pedestrians to cross a main road during the minor road green phase. Other signals under CTDOT jurisdiction accommodate pedestrians using an “Exclusive” phasing scheme, where pedestrians are provided with special signal faces (walk and don’t walk, or the respective icons) along with their own phase during which all motorized traffic is stopped. Some of these signals operating under exclusive phasing are combined with countdown timers to indicate how much time is left in the pedestrian walk phase (this is now required by MUTCD Section 4E.07[1]). Other than some rare exceptions, these are the only two types of phasing for pedestrians at CTDOT owned signals.

Recent research has investigated the differences in pedestrian-vehicle interaction and crash count at 42 intersections in Connecticut equipped with either side street green or exclusive pedestrian signal phasing. Pedestrians crossing at each intersection were observed and classified according to the severity of interactions with motor vehicles as well as whether they complied with the pedestrian signal indication (or green/red light for side street green signals). Interaction severity was defined in a range from no interaction to potential conflict, minor conflict and serious conflict, in which a collision between the pedestrian and vehicle was imminent. Observation intersections were selected to represent both types of signal phasing while controlling for other physical characteristics. Pedestrians crossing on the walk signal at an exclusive signal experienced fewer severe conflicts compared to those crossing on the green light with side street green phasing; however, pedestrians crossing on a green light where an exclusive phase was available experienced more severe conflicts. Crash experience at all intersections was also investigated. Intersections with side street green phasing had fewer total pedestrian crashes than those with exclusive phasing, but overall had more crashes involving an injury of severity level A (serious) or B (minor).

That same study also compared pedestrian compliance at traffic signals at the two types of pedestrian phasing. Specifically, it investigated whether or not there were differences between pedestrian compliance at the two types of phasing and whether these differences persisted when compliance at exclusive phasing signals was evaluated as if they had side street green phasing (i.e., crossing on the green phase was deemed to be “compliant”). Pedestrian compliance was significantly higher at intersections with side street green phasing than at those with exclusive phasing, but this difference was not significant when compliance

[1] MUTCD Section 4E.07 can be accessed using the following URL: https://mutcd.fhwa.dot.gov/htm/2009/part4/part4e.htm.

at exclusive phase intersections was evaluated as if they had side street green phasing. This suggests that pedestrians treat exclusive phase intersections as though they have side street green phasing, rendering the safety benefits of exclusive pedestrian phasing elusive.

In light of these findings, CTDOT is moving forward with the conversion of signals with side street green phasing to "concurrent" phasing, in which pedestrians continue to cross the major road during the minor road green phase, but they are given "Walk" and "Don't Walk" indications (expressed as icons) in conjunction with countdown timers. The motivation for CTDOT to consider this new signal operation is to provide better consistency in communication to pedestrians and motorists about what to expect from the signal operation and when pedestrians should and should not be crossing the road while avoiding misleading pedestrians into believing they do not need to interact with motor vehicles while crossing the road. However, because the "Walk" and "Don't Walk" signal indications have up to now only been used with exclusive phasing, CTDOT is concerned about both motorist and pedestrian confusion at the concurrent phase signals. Specifically, pedestrians are conditioned to expect to have exclusive use of the crosswalk with no vehicles turning across their path when a "Walk" indication is showing (other than legal right turns on red), and motorists are conditioned to expect no pedestrians crossing the street when making permitted left or right turns during their green phase. This report investigates the effects on pedestrian safety due to this change in intersection signal hardware, including the development of preferred practices to address any potential negative impacts associated with implementing this change across the network of traffic signals throughout the State.

1.2 Project Objectives and Scope

The objective of this project was to carry out a safety evaluation of the proposed conversion of intersections owned by CTDOT operating under side street green pedestrian phasing to concurrent pedestrian phasing. It is noted that because the proposed use of "Walk" and "Don't Walk" signal indications with concurrent pedestrian phase operation is completely new to many Connecticut motorists and pedestrians, it was essential to include an educational campaign that includes testing of public understanding of the new signal operation. Further, in order to properly attribute observed outcomes to the treatment, it was necessary to set up a before and after study design with control locations that remain using Side Street Green operation and including locations that implement concurrent phasing both with and without auxiliary signage warning pedestrians and motorists that they will be sharing a signal phase. We also include locations with exclusive pedestrian phasing for additional comparison, and to confirm or update findings from the previous study of how the new concurrent pedestrian phasing compares with the exclusive pedestrian phasing in terms of improving pedestrian safety.

The safety evaluation included observation and analysis of differences for both treatment and control intersections in the distribution of pedestrian-vehicle interaction severity defined according to the direct observation of the vehicle and pedestrian trajectories.

The intersections received one of four treatments as illustrated in Figure 1:

a) Conversion from side street green to concurrent phasing with auxiliary signage.
b) Conversion from side street green to concurrent phasing without auxiliary signage.
c) Existing side street green operation with no conversion.
d) Existing exclusive pedestrian phasing operation with no conversion.

(a) Concurrent phasing with auxiliary signage

(b) Conncurrent phasing without auxiliary signage

(c) Side street green phasing

(d) Exclusive phasing

Figure 1 Illustration of the Four Types of Pedestrian Signal Phasing

This project included the following phased scope of work:

Phase I: Identification of locations for treatment, preparation of the study design, and collection of before data.

Phase II: Installation of new signal devices at treatment locations, both with and without auxiliary signage, along with an educational campaign and testing of public understanding.

Phase III: Collection of after data, analysis of before and after data, and completion of final report.

The rest of this report describes the work that was conducted in each of these phases of the project.

CHAPTER 2 STUDY DESIGN AND DATA COLLECTION

2.1 Experimental Study Design

The first task was to obtain a list of CTDOT maintained signalized intersections that operate with side street green pedestrian phasing from which treatment and comparison sites could be chosen. Once the project team acquired the list of candidate treatment intersections, the team selected intersections for observation in groups according to characteristics that were expected to be associated with pedestrian behavior and safety, including general level of pedestrian activity, commercial or residential location, and relative population density. This step was critical to confidently associate any observed differences in safety outcomes with the targeted treatment.

To help select observation locations, the following characteristics of the candidate locations were assembled from archival sources:

- Traffic volumes and AADT, from CTDOT archives; most recent year available.
- Crossing distances for the crosswalks (or pedestrian crossing zone) spanning the major road approach legs, in feet, collected from GoogleEarth®.
- Physical characteristics, namely, the number of vehicle lanes, the presence of crosswalks or sidewalks, and the presence of a median, collected using GoogleEarth®.

Using this information, the team matched three intersections from the list based on similar physical characteristics, such as the presence of crosswalks or sidewalks, crossing width, and the number of vehicle lanes. For each cohort of three intersections, the team selected an intersection with similar characteristics and exclusive pedestrian signal phasing as an additional comparison. In summary, the team selected ten such cohort groups of four intersections each, with one intersection in each cohort group to receive one of the four treatments (introduced previously but repeated here for convenience):

1. Conversion from side street green to concurrent phasing with auxiliary signage
2. Conversion from side street green to concurrent phasing without auxiliary signage.
3. Side street green without conversion (first comparison group).
4. Exclusive phasing without conversion (second comparison group).

Initially, the total number of observation sites was 40, with 20 of these intersections to be selected for installation of new pedestrian signals (i.e., 10 conversions to concurrent phasing with auxiliary signage, and 10 conversions to concurrent without auxiliary signage). Table 1 lists the intersections for treatment and comparison and was shared with CTDOT and approved before data collection was initiated.

Table 1 Characteristics of Observation Locations by Cohort Group

Group	Intersection Number	Location	Town	Crosswalks	Sidewalks	Number of Lanes	Crossing Distance (ft)	AADT (veh/day)
Group 1	084-203	ROUTE 25 AT PURDY HILL RD AND JUDD RD	MONROE	None	None	3	48	20,600
	027-215	U.S ROUTE 1 AT MEADOW RD & MALLARD LN.	CLINTON	None	1 Side	3	83	10,700
	034-244	U.S. ROUTE 202/6 AT KENOSIA AVE	DANBURY	None	None	3	47	18,100
	156-202	ROUTE 1 AT FAIRFAX ST	WEST HAVEN	None	2 Sides	4	54	18,900
Group 2	011-254	ROUTE 189 AT JEROME AVENUE	BLOOMFIELD	Some	2 Sides	2	52	9400
	044-218	ROUTE 161 AT SOCIETY ROAD	EAST LYME	Some	1 Side	3	52	16,600
	156-262	ROUTE 162 AT SOUTH STREET	WEST HAVEN	Some	2 Sides	2	45	6000
	058-255	ROUTE 117 AT INDIAN FIELD RD & DR TO LIBRARY & CENTER	GROTON	Some	2 Sides	3	54	14,000
Group 3	059-230	ROUTE 1 AT GUILFORD COMMONS DRIVE	GUILFORD	Some	1 Side	3	55	11,900
	158-218	ROUTE 1 AT WEST PARISH RD & CEDAR STREET	WESTPORT	Some	2 Sides	4	63	21,900
	102-254	ROUTE 1 AT I-95 SB ON/OFF RAMPS	NORWALK	Some	2 Sides	5	58	20,900
	138-204	ROUTE 1 AT BROADBRIDGE AVE.	STRATFORD	Some	2 Sides	3	53	13,900
Group 4	105-222	ROUTE 154 AT RESERVOIR RD & PVT. DR.	OLD SAYBROOK	None	None	3	58	14,000
	126-208	SR 714 AT NELLS ROCK RD. & PLATT RD.	SHELTON	None	None	3	59	17,400
	126-242	SR 714 AT DR TO SHELTON SQUARE SOUTH & DUCHESS REST.	SHELTON	None	None	4	50	16,000
	105-224	ROUTE 166 AT DRIVE TO MAX'S PLACE & PRIVATE DRIVE	OLD SAYBROOK	Some	2 Sides	4	53	12,400
Group 5	015-213	ROUTE 1 AT WOOD AVENUE	BRIDGEPORT	All	2 Sides	2	49	14,000
	015-231	ROUTE 1 AT WELLS STREET	BRIDGEPORT	All	2 Sides	2	46	13,900
	015-211	ROUTE 1 AT CLINTON & BROOKLAWN AVE	BRIDGEPORT	All	2 Sides	2	50	15,300
	015-214	ROUTE 1 AT PARK AVE	BRIDGEPORT	All	2 Sides	4	58	14,700
Group 6	163-236	ROUTE 6 AT NORTHRIDGE DR & PVT. DR.	WINDHAM	None	2 Sides	5	84	20,500
	083-225	ROUTE 1 AT I-95 NB OFF-RAMP & HOME ACRES AVE	MILFORD	None	2 Sides	6	87	34,600
	158-229	ROUTE 1 AT S.R. 476 (SHERWOOD ISLAND CONNECTOR)	WESTPORT	None	2 Sides	5	79	21,900
	050-202	RTE 135 (STILLSON RD) AT STILLSON RD	FAIRFIELD	All	2 Sides	5	70	19,400

Group	Intersection Number	Location	Town	Crosswalks	Sidewalks	Number of Lanes	Crossing Distance (ft)	AADT (veh/day)
Group 7	058-220	ROUTE 184 AT KINGS HIGHWAY & WAL-MART SHOPPING CENTER	GROTON	Some	2 Sides	5	92	13,400
	083-274	ROUTE 1 AT SHOP RITE PLAZA DRIVE	MILFORD	Some	2 Sides	5	62	17,100
	100-206	ROUTE 5 AT FRANKLIN ST & DRAZEN SHOPPING CENTER	NORTH HAVEN	Some	2 Sides	5	75	18,400
	043-202	RTE 80 AT MILL ST & THOMPSON ST	EAST HAVEN	All	2 Sides	5	77	19,100
Group 8	058-251	ROUTE 1 AT MAXSON RD & DR TO LIGHTHOUSE SQUARE	GROTON	Some	2 Sides	5	64	21,700
	050-219	ROUTE 1 AT BRENTWOOD AVE & LONGFELLOW AVE	FAIRFIELD	Some	2 Sides	4	60	19,200
	015-271	ROUTE 1 AT DEWEY, BRIARWOOD & CARTRIGHT STS HOWARD	BRIDGEPORT	All	2 Sides	4	66	13,200
	050-207	ROUTE 1 AT RUANE STREET	FAIRFIELD	All	2 Sides	4	64	20,000
Group 9	035-209	ROUTE 1 AT CENTER ST & SQUAB LN	DARIEN	Some	2 Sides	2	45	14,100
	035-209	ROUTE 1 AT WEST AVE & MECHANIC ST	DARIEN	Some	2 Sides	2	50	15,000
	158-211	ROUTE 1 AT ROUTE 33 (WILTON RD & RIVERSIDE AVE.)	WESTPORT	Some	2 Sides	4	56	18,800
	126-202	RTE 108 & RTE 110 (HOWE AVE) & CENTER STREET	SHELTON	All	2 Sides	3	52	13,500
Group 10	163-230	ROUTE 66 AT MAYO & ALEBERT STREET'S	WINDHAM	None	2 Sides	2	58	7800
	082-240	ROUTE 217 AT WESTLAKE DR & EASTLAKE DR	MIDDLETOWN	None	2 Sides	3	64	13,600
	080-209	ROUTE 64 AT GLENWOOD AVE, & TUCKER HILL RD.	MIDDLEBURY	Some	2 Sides	2	52	15,300
	163-237	ROUTE 66 AT MAIN ST & ASH STREET	WINDHAM	All	2 Sides	2	43	11,900

2.2 Collection of Before Data

Once the observation sites were selected, the following items were observed at each intersection:

- Interactions between pedestrians and vehicles
- Hourly vehicle volumes
- The time each pedestrian spent waiting before crossing and the amount of time spent crossing the street.
- Pedestrian signal phase during which a pedestrian crosses the street.
- The vehicle signal phase during which each pedestrian crossed the street.

The site observation periods for each study intersection were between 4 and 6 hours long within the time span of 12 to 9 PM, varying by location, which allowed for the collection of data in both light and dark conditions. Two observers collected data at each intersection; one person recorded the pedestrian waiting and crossing times and the type of vehicle interaction, while the other counted vehicles passing through the crosswalk. Interactions between pedestrians and motor vehicles were observed at the crossings of the major road and classified by four interaction definitions: undisturbed crossing, potential conflict, minor conflict, and serious conflict. The conflict types were categorized using the Swedish Traffic Conflict Technique (TCT) (Laureshyn and Várhelyi, 2018). All observers were trained in this technique and several test runs were conducted to check the consistency of data collection among observers in recording the interaction types. Definitions of the four interaction types are as follows:

- **Undisturbed passage:** Here, pedestrians cross the road without any possibility of getting into a collision with any motor vehicles. An undisturbed passage occurs when vehicles are completely stopped during a red light and a pedestrian crosses the street, or when a pedestrian crosses the street with no vehicles in the vicinity.
- **Potential conflict:** A potential conflict occurs when the pedestrian and vehicle interact with each other but there is a relatively low likelihood of a collision occurring. For example, when a vehicle is already slowing to a stop or when the driver of the vehicle and the pedestrian makes eye contact before or while crossing the street.
- **Minor conflict:** A minor conflict occurs when there is a small chance of a collision between the pedestrian and a motor vehicle. During a minor conflict, vehicle speed is low, which allows the driver to maneuver out of the pedestrian's path or come to a quick stop if that is required to avoid hitting the pedestrian in the crosswalk. The vehicle normally would stop a few feet away from the pedestrian during a minor conflict. Because of the low speed of the moving vehicle, this type of conflict would be unlikely to result in a fatality if it were to become a collision.

- **Serious conflict:** A serious conflict occurs when the pedestrian and a vehicle are on a collision course with very late evasive action taken to avoid the collision. In this type of conflict, a vehicle must make a strong evasive action in order to avoid a collision with a pedestrian, or a pedestrian must make an erratic, unplanned movement (e.g., jumping back onto the sidewalk or springing out of the vehicle's path) in order to avoid a collision with a vehicle.

During observations at each study intersection, every pedestrian who crossed the major road was classified into one of the above four interaction categories, such that the total of all categories gives the pedestrian crossing volume. In addition to the interaction with motor vehicles, each pedestrian's compliance with the signal control was also observed, defined as follows (in order of increasing level of violation and potential conflict with vehicles); note that in these definitions we delineate what sort of indication is shown for vehicles followed by the indication (or permissiveness) for pedestrians:

- **Red/Walk:** In the direction the pedestrian is crossing, the vehicle light is red and there is a walk signal for pedestrians. This only occurs at a signal with exclusive pedestrian phasing. The pedestrian is compliant with the intersection crossing rules.

- **Green/Walk:** In the direction the pedestrian is crossing, the vehicle light is green and there is a walk signal or auxiliary 8-inch circular green light for pedestrians, or there are no other pedestrian crossing signals. This occurs at a signal with side street green pedestrian phasing or the proposed concurrent phasing. The pedestrian is compliant with the intersection crossing rules because there is no exclusive pedestrian phase provided.

- **Green/Don't Walk:** In the direction the pedestrian is crossing the vehicle light is green and there is a Don't Walk signal for pedestrians. This only occurs at a signal with exclusive pedestrian phasing. The pedestrian is NOT compliant with the intersection crossing rules, even though the traffic operating conditions are identical to the Green/Walk condition, which is legal at an intersection with side street green or the proposed concurrent phasing.

- **Red/Don't Walk:** In the direction the pedestrian is crossing, the vehicle light is red and there is a Don't Walk signal for pedestrians, or no signals provided for pedestrians. This can occur at either type of signal. The pedestrian is NOT compliant with the intersection crossing rules. This will also include all pedestrians crossing more than fifteen feet outside a marked or unmarked crosswalk. An unmarked crosswalk is defined as an area 15 ft wide spanning the road between two adjacent street corners.

During the first year of data collection, observations were completed at 36 of the 40 selected sites. Zero pedestrians were observed at a number of sites, including all of cohort group 2. Due to this and continuing delays due to inclement weather, observations at the intersections in cohort group 6, which were all auto-oriented locations that were also not expected to have any pedestrian activity based on the experience with cohort group 2, were canceled. As a consequence, cohort groups 2 and 6 were excluded from the project and the study design was reduced to eight cohorts, for a total of 32 intersections. Each of the remaining cohort groups included three intersections with side street green pedestrian phasing and one with exclusive pedestrian phasing.

Of the three side street green intersections in each group, two were selected for installation of concurrent phasing, one with auxiliary signage warning pedestrians and vehicles to watch for one another during the green/pedestrian phase, and the other with no auxiliary signage for a total of 16 installations. Table 2 shows details for all of the sites and the specific treatment that was proposed for each intersection.

2.3 Educational Campaign

An important component of the study was to gauge public understanding of the proposed concurrent pedestrian signal operation and facilitate the public's adoption and successful use of the new signals. An educational campaign was planned to inform the public of the new signal installations taking place around the state and provide detailed instructions in how to use the signals, and what is expected of pedestrians and motorists at the intersections where the signals are located. Prior to the release of the educational campaign, the project team developed a comprehension survey to distribute among Connecticut residents to assess public perception and understanding of the planned implementation and new signal operations. Collection of this information was helpful in setting expectations for behavior and for the development of targeted messaging related to the concurrent pedestrian signal installation.

Participants were recruited online through the use of a third-party source, Qualtrics, Inc. Potential participants were screened to exclude those who were under 18 years of age or living outside of Connecticut. Recruitment was selective to reach a representative sample of the state population. We received 525 responses to the survey, 428 of which were completed sufficiently to consider in the analysis of the results. Responses to questions about participant's crossing behavior (i.e., how often do you cross during the "don't walk" phase?) were collected. In response to questions related to other risky walking behaviors, 20.1% replied "always" and 39.5% replied "sometimes" to how often they cross roads with high traffic volume. Over half reported running sometimes (44.6%) or always (9.6%) while crossing the road. Descriptive statistics for each question are shown in Table 3 and Appendix B.

Questions pertaining to the pedestrian signals asked participants to provide feedback on aspects such as the color of the educational materials to the clarity of the information presented. Participants were initially shown images of three crosswalks with the different phasing types (exclusive, side street green, concurrent) and asked to rank their familiarity with each one. More than half of the participants said they were "very familiar" or "extremely familiar" with all phasing types, with 63.1% for exclusive, 52.1% for side street green, and

59.6% for concurrent. Short form text boxes were added for participants to explain in their own words what they understood the brochure to be about.

Table 2 List of Intersections Observed with Total Pedestrian Counts and Proposed Treatment

Group	Intersection Number	Location	Town	Number of Pedestrians Observed	Date Observed (2021)	Treatment
Group 1	084-203	ROUTE 25 AT PURDY HILL RD AND JUDD RD	MONROE	0	14-Jul	Side Street Green
	027-215	U.S ROUTE 1 AT MEADOW RD & MALLARD LN.	CLINTON	3	3-Aug	Concurrent w/ Signage
	034-244	U.S. ROUTE 202/6 AT KENOSIA AVE	DANBURY	7	13-Jul	Concurrent w/o Signage
	156-202	ROUTE 1 AT FAIRFAX ST	WEST HAVEN	13	10-Nov	Exclusive
Group 2	011-254	ROUTE 189 AT JEROME AVENUE	BLOOMFIELD	0	15-Jul	Side Street Green
	044-218	ROUTE 161 AT SOCIETY ROAD	EAST LYME	0	1-Oct	Side Street Green
	156-262	ROUTE 162 AT SOUTH STREET	WEST HAVEN	0	6-Oct	Side Street Green
	058-255	ROUTE 117 AT INDIAN FIELD RD & DR TO LIBRARY & CENTER	GROTON	0	22-Jul	Exclusive
Group 3	059-230	ROUTE 1 AT GUILFORD COMMONS DRIVE	GUILFORD	0	3-Sep	Side Street Green
	158-218	ROUTE 1 AT WEST PARISH RD & CEDAR STREET	WESTPORT	2	8-Sep	Concurrent w/ Signage
	102-254	ROUTE 1 AT I-95 SB ON/OFF RAMPS	NORWALK	4	8-Sep	Concurrent w/o Signage
	138-204	ROUTE 1 AT BROADBRIDGE AVE.	STRATFORD	13	10-Nov	Exclusive
Group 4	105-222	ROUTE 154 AT RESERVOIR RD & PVT. DR.	OLD SAYBROOK	0	17-Aug	Side Street Green
	126-208	SR 714 AT NELLS ROCK RD. & PLATT RD.	SHELTON	8	27-Jul	Concurrent w/ Signage
	126-242	SR 714 AT DR TO SHELTON SQUARE SOUTH & DUCHESS REST.	SHELTON	3	5-Aug	Concurrent w/o Signage
	105-224	ROUTE 166 AT DRIVE TO MAX'S PLACE & PRIVATE DRIVE	OLD SAYBROOK	2	17-Nov	Exclusive
Group 5	015-213	ROUTE 1 AT WOOD AVENUE	BRIDGEPORT	5	23-Jul	Side Street Green
	015-231	ROUTE 1 AT WELLS STREET	BRIDGEPORT	13	28-Jul	Concurrent w/o Signage
	015-211	ROUTE 1 AT CLINTON & BROOKLAWN AVE	BRIDGEPORT	23	4-Aug	Concurrent w/ Signage
	015-214	ROUTE 1 AT PARK AVE	BRIDGEPORT	32	11-Aug	Exclusive
Group 6	163-236	ROUTE 6 AT NORTHRIDGE DR & PVT. DR.	WINDHAM	*na*	*na*	Side Street Green
	083-225	ROUTE 1 AT I-95 NB OFF-RAMP & HOME ACRES AVE	MILFORD	*na*	*na*	Side Street Green
	158-229	ROUTE 1 AT S.R. 476 (SHERWOOD ISLAND CONNECTOR)	WESTPORT	*na*	*na*	Side Street Green
	050-202	RTE 135 (STILLSON RD) AT STILLSON RD	FAIRFIELD	*na*	*na*	Exclusive
Group 7	058-220	ROUTE 184 AT KINGS HIGHWAY & WAL-MART SHOPPING CENTER	GROTON	7	29-Oct	Concurrent w/o Signage
	083-274	ROUTE 1 AT SHOP RITE PLAZA DRIVE	MILFORD	2	13-Oct	Concurrent w/ Signage
	100-206	ROUTE 5 AT FRANKLIN ST & DRAZEN SHOPPING CENTER	NORTH HAVEN	0	15-Oct	Side Street Green
	043-202	RTE 80 AT MILL ST & THOMPSON ST	EAST HAVEN	5	26-Jul	Exclusive

Group	Intersection Number	Location	Town	Number of Pedestrians Observed	Date Observed (2021)	Treatment
Group 8	058-251	ROUTE 1 AT MAXSON RD & DR TO LIGHTHOUSE SQUARE	GROTON	3	29-Oct	Concurrent w/o Signage
	050-219	ROUTE 1 AT BRENTWOOD AVE & LONGFELLOW AVE	FAIRFIELD	1	22-Oct	Concurrent w/ Signage
	015-271	ROUTE 1 AT DEWEY, BRIARWOOD & CARTRIGHT STS HOWARD	BRIDGEPORT	8	5-Nov	Side Street Green
	050-207	ROUTE 1 AT RUANE STREET	FAIRFIELD	38	12-Aug	Exclusive
Group 9	035-209	ROUTE 1 AT CENTER ST & SQUAB LN	DARIEN	76	27-Oct	Concurrent w/o Signage
	035-209	ROUTE 1 AT WEST AVE & MECHANIC ST	DARIEN	28	3-Nov	Concurrent w/ Signage
	158-211	ROUTE 1 AT ROUTE 33 (WILTON RD & RIVERSIDE AVE.)	WESTPORT	25	20-Oct	Side Street Green
	126-202	RTE 108 & RTE 110 (HOWE AVE) & CENTER STREET	SHELTON	17	18-Nov	Exclusive
Group 10	163-230	ROUTE 66 AT MAYO & ALEBERT STREET'S	WINDHAM	8	3-Sep	Concurrent w/o Signage
	082-240	ROUTE 217 AT WESTLAKE DR & EASTLAKE DR	MIDDLETOWN	9	8-Sep	Concurrent w/ Signage
	080-209	ROUTE 64 AT GLENWOOD AVE, & TUCKER HILL RD.	MIDDLEBURY	4	29-Sep	Side Street Green
	163-237	ROUTE 66 AT MAIN ST & ASH STREET	WINDHAM	34	11-Aug	Exclusive

Note: *na* = not applicable

Table 3 Descriptive statistics of survey questions

N (Row %)	Never	Rarely	Sometimes	Always/Often
How often do you, as a pedestrian, cross roads with high traffic volume?	41 (9.6)	132 (30.8)	169 (39.5)	86 (20.1)
When walking, how often do you cross the street at locations other than intersections and crosswalks (i.e., middle of a block, unmarked areas, etc.)?	39 (9.1)	165 (38.6)	177 (41.4)	47 (11.0)
When crossing the street at an intersection or crosswalk with a pedestrian signal, how often do you cross during the "don't walk" phase?	125 (29.2)	147 (34.3)	133 (31.1)	23 (5.4)
When walking on a road with a sidewalk, how often do you walk on the road instead of the sidewalk?	198 (46.3)	136 (31.8)	71 (16.6)	23 (5.4)
How often do you cross the road without watching for cars?	345 (80.6)	37 (8.6)	21 (4.9)	25 (5.8)
How often do you run while crossing the road?	89 (20.8)	107 (25.0)	191 (44.6)	41 (9.6)

N (Row %)	Much lower probability	Lower probability	Same probability	Higher probability	Much higher probability
Compared to other pedestrians, what is the probability that you will be involved in an accident while crossing the street?	153 (35.7)	169 (39.5)	69 (16.1)	32 (7.5)	5 (1.2)
How often do you use each of the following modes of transportation?	**Every day**	**A few times a week**	**A few times a month**	**Once a month or less**	**Never**
- Driving	269 (62.9)	99 (23.1)	29 (6.8)	17 (4.0)	14 (3.3)
- Walking	128 (29.9)	155 (36.2)	62 (14.5)	50 (11.7)	33 (7.7)
- Cycling	13 (3.0)	41 (9.6)	74 (17.3)	74 (17.3)	223 (52.1)
- Public Transit	15 (3.5)	41 (9.6)	50 (11.7)	90 (21.0)	232 (54.2)
N (Row %)	**Not familiar at all**	**Slightly familiar**	**Moderately familiar**	**Very familiar**	**Extremely familiar**
How familiar are you with Exclusive Phasing Pedestrian Signals?	37 (8.6)	44 (10.3)	77 (18.0)	125 (29.2)	145 (33.9)
How familiar are you with Side Street Green Pedestrian Signals?	53 (12.4)	61 (14.3)	91 (21.3)	99 (23.1)	124 (29.0)
How familiar are you with Concurrent Phasing Pedestrian Signals?	38 (8.9)	48 (11.2)	87 (20.3)	115 (26.9)	140 (32.7)

Results from the survey were used to shape the final messaging and public education of the concurrent pedestrian signals for both pedestrians and drivers. Using a package in the statistical software RStudio called quanteda, short answer responses were analyzed to create word clouds of the most common phrases or words in response to Q24: "Tell us in a few words what the brochure is about", Q25: What did you like about the brochure?", and Q26: What could be improved about the brochure?". Areas where respondents showed a lower level of understanding were examined closely and revised for the final product. Figure 2 depicts the final version of the educational material created and printed on a 5 x 7 postcard and an 8.5 x 11 tri-fold brochure.

Figure 2 Final Educational Brochure

Once all of the installations were complete, a thirty-day targeted educational campaign was executed to acquaint motorists and pedestrians in the area with the new signal operation. The project team printed 750 copies of the brochure and postcard (375 each) to be distributed to residents in the areas surrounding the ten signal installation sites. The research team also contacted local media outlets to run stories informing the public of the new signals in their area and include information from the brochure to explain signal operation and expectations from drivers and pedestrians. Media stories were run in the Hartford Courant, WSHU Public Radio, Hearst Connecticut, and CT Insider.

2.4 Collection of After Data

Personnel at CTDOT Maintenance Districts 1, 3, and 4 installed the hardware and software associated with implementing the treatments according to the study design in Table 2. Physical installation began in April 2022 and was completed in September 2022. Due to issues that arose during the installation phase, only 10 of the 16 proposed intersections were actually converted to concurrent phasing. The study design was adjusted to accommodate these changes in the installation plan, including cohort group 3 being removed from the analysis.

Data describing the after conditions at each intersection, both treated and untreated, were collected using the same protocols as for the before data. Whenever possible, the data were collected during the same months of the year as the before data collected was conducted and traffic volume data will be updated based on the current conditions. No changes in road characteristics, aside from the conversion from side street green to current pedestrian phasing at treatment intersections, were observed at any of the project sites. A summary of the data collected during the after period and the treatment actually assigned to each intersection can be seen in Table 4**.** The data collected during the before period were added to this table for comparison.

Table 4 Summary of Observations

Group	Intersection No.	Town	Pedestrians Observed (2021)	Date Observed (2021)	Pedestrians Observed (2022)	Date Observed (2022)	Vehicle Volume (veh/h) (2021)	Vehicle Volume (veh/h) (2022)	Treatment
Group 1	084-203	MONROE	0	14-Jul	0	14-Oct	1490	1468	Side Street Green
	027-215	CLINTON	3	3-Aug	2	27-Jul	871	862	Concurrent w/ Signage
	034-244	DANBURY	7	13-Jul	1	5-Jul	1118	1075	Concurrent w/o Signage
	156-202	WEST HAVEN	13	10-Nov	26	29-Sep	1623	1374	Exclusive
Group 4	105-222	OLD SAYBROOK	0	17-Aug	0	28-July	994	1333	Side Street Green
	126-208	SHELTON	8	27-Jul	1	6-Oct	1100	1293	Concurrent w/ Signage
	126-242	SHELTON	3	5-Aug	1	27-Sep	998	1106	Side Street Green
	105-224	OLD SAYBROOK	2	17-Nov	4	4-Aug	925	962	Exclusive
Group 5	015-213	BRIDGEPORT	5	23-Jul	20	20-Oct	923	980	Side Street Green
	015-231	BRIDGEPORT	13	28-Jul	24	28-Sep	960	946	Side Street Green
	015-211	BRIDGEPORT	23	4-Aug	17	26-Oct	480	1078	Concurrent w/ Signage
	015-214	BRIDGEPORT	32	11-Aug	82	12-Oct	895	986	Exclusive
Group 7	058-220	GROTON	7	29-Oct	9	17-Aug	1310	1201	Concurrent w/o Signage
	083-274	MILFORD	2	13-Oct	6	27-Oct	1176	1485	Side Street Green
	100-206	NORTH HAVEN	0	15-Oct	6	18-Oct	1814	1688	Side Street Green
	043-202	EAST HAVEN	5	26-Jul	5	14-Jul	1118	1134	Exclusive
Group 8	058-251	GROTON	3	29-Oct	4	25-Oct	1601	1492	Concurrent w/o Signage
	050-219	FAIRFIELD	1	22-Oct	2	25-Sep	1413	1056	Side Street Green
	015-271	BRIDGEPORT	8	5-Nov	12	19-Oct	763	950	Side Street Green
	050-207	FAIRFIELD	38	12-Aug	57	3-Nov	1196	1370	Exclusive
Group 9	035-209	DARIEN	76	27-Oct	67	9-Nov	714	750	Concurrent w/o Signage
	035-209	DARIEN	28	3-Nov	25	3-Nov	1020	1281	Concurrent w/ Signage
	158-211	WESTPORT	25	20-Oct	38	21-Sep	1148	1222	Side Street Green
	126-202	SHELTON	17	18-Nov	29	27-Oct	746	711	Exclusive
Group 10	163-230	WINDHAM	8	3-Sep	4	11-Oct	602	542	Concurrent w/o Signage
	082-240	MIDDLETOWN	9	8-Sep	17	6-Oct	729	773	Concurrent w/ Signage
	080-209	MIDDLEBURY	4	29-Sep	6	15-Aug	983	1042	Side Street Green
	163-237	WINDHAM	34	11-Aug	12	30-Sep	818	886	Exclusive

CHAPTER 3 ANALYSIS OF FINDINGS

3.1 Preparation of Data

Since the data were collected individually for each intersection in both the before and after periods, the data were combined to form a single dataset. The descriptive statistics for the continuous variables that were collected can be seen in Table 5 and the descriptive statistics for categorical or discrete variables can be found in Table 6. Violin plots of each continuous variable collected in this study for both conflict and non-conflict observations are displayed in Figure 3. Similarly, violin plots of each continuous variable for compliant and noncompliant crossings can be seen in Figure 4. Since no serious conflicts were observed, each pedestrian observation was classified based on whether a minor conflict occurred with a vehicle; observations categorized as an undisturbed passage or a potential conflict were considered to be non-conflict events, while observations classified as a minor conflict were designated as conflict events. A dummy variable was created to denote this; a value of 1 was given to all conflict events, while 0 was given to all non-conflict events. Along with this, a second binary variable was created to indicate if a person was compliant with the appropriate pedestrian signals; individuals that crossed during the “Green” phase at side street green intersections or the “Walk” phase at exclusive or concurrent phase intersections were considered to be compliant, while pedestrians who crossed during the “Red” and “Don’t Walk” phases were classified as noncompliant.

Table 5 Descriptive statistics for continuous variables.

Variable	Mean	Minimum	Maximum	Standard Deviation
Wait Time (s) The observed amount of time a pedestrian spent waiting before crossing the street.	23.79	0.00	163.54	25.77
Crossing Time (s) The observed amount of time that a pedestrian took to cross the street.	11.02	1.51	41.73	4.36
Crossing Distance (ft) The distance from curb cut to curb cut of the pedestrian crossing at each intersection.	54.66	43	92	9.37
Observed Vehicle Volume (veh/h) The recorded average vehicle volume per hour at a pedestrian crossing during each observation period.	993	480	1688	258.18

Table 6 Descriptive statistics for categorical or discrete variables.

Variable	Levels/Categories	Frequency	Percent of Observations (%)
Interaction Type The type of interaction a pedestrian experienced while crossing the street.	Undisturbed Passage Potential Conflict Minor Conflict Serious Conflict	568 255 27 0	66.8 30.0 3.2 0.0
Pedestrian Compliance A dummy variable that indicates if a pedestrian was compliant with the signal control.	Noncompliant Compliant	352 498	41.4 58.6
Phasing The type of pedestrian signal phasing that is present at each pedestrian crossing.	Side Street Green Exclusive Concurrent w/ Signage Concurrent w/o Signage	347 356 62 85	40.8 41.9 7.3 10.0
Weather The type of weather recorded during each observation session.	Cloudy Clear	129 721	15.2 84.8
Median A dummy variable that indicates the presence of a median at a specific pedestrian crossing.	Not Present Present	740 110	87.1 12.9
Crosswalks A dummy variable that indicates the presence of a painted crosswalk.	None Any	103 747	12.1 87.9
Sidewalks A dummy variable that indicates the presence of at least one sidewalk at an intersection.	None Any	21 829	2.5 97.5
Number of Lanes The number of vehicle lanes a pedestrian walked across during each crossing.	2 3 4 5	366 94 342 48	43.1 11.1 40.2 5.6
Month The month during which an observation was recorded.	July August September October November	46 130 133 324 217	5.4 15.3 15.7 38.1 25.5
Day of Week The day of the week associated with each pedestrian crossing event.	Sunday Monday Tuesday Wednesday Thursday Friday Saturday	2 0 39 306 436 35 32	0.2 0.0 4.6 36.0 51.3 4.1 3.8

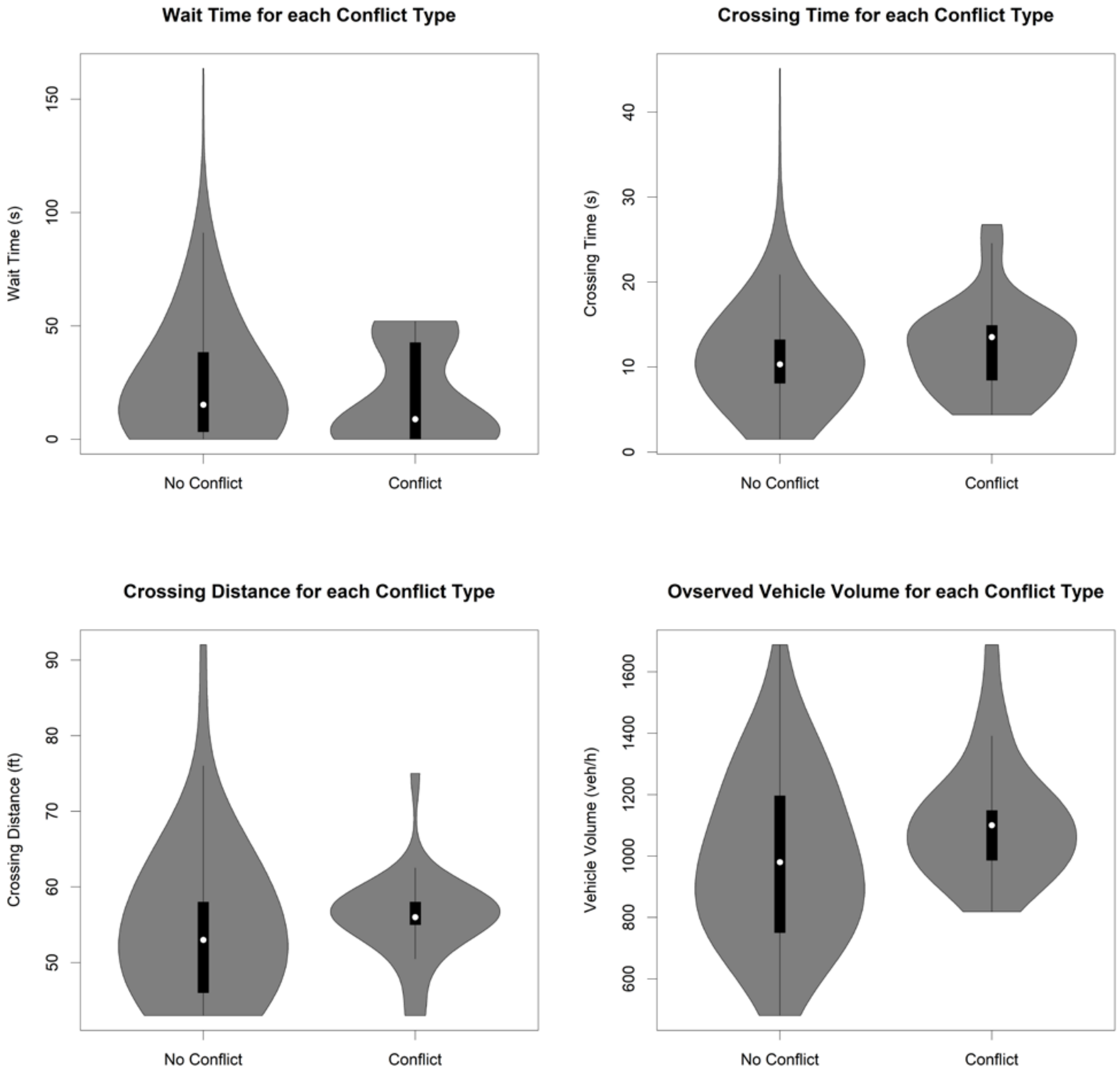

Figure 3 Violin plots of continuous variables for conflict and non-conflict events.

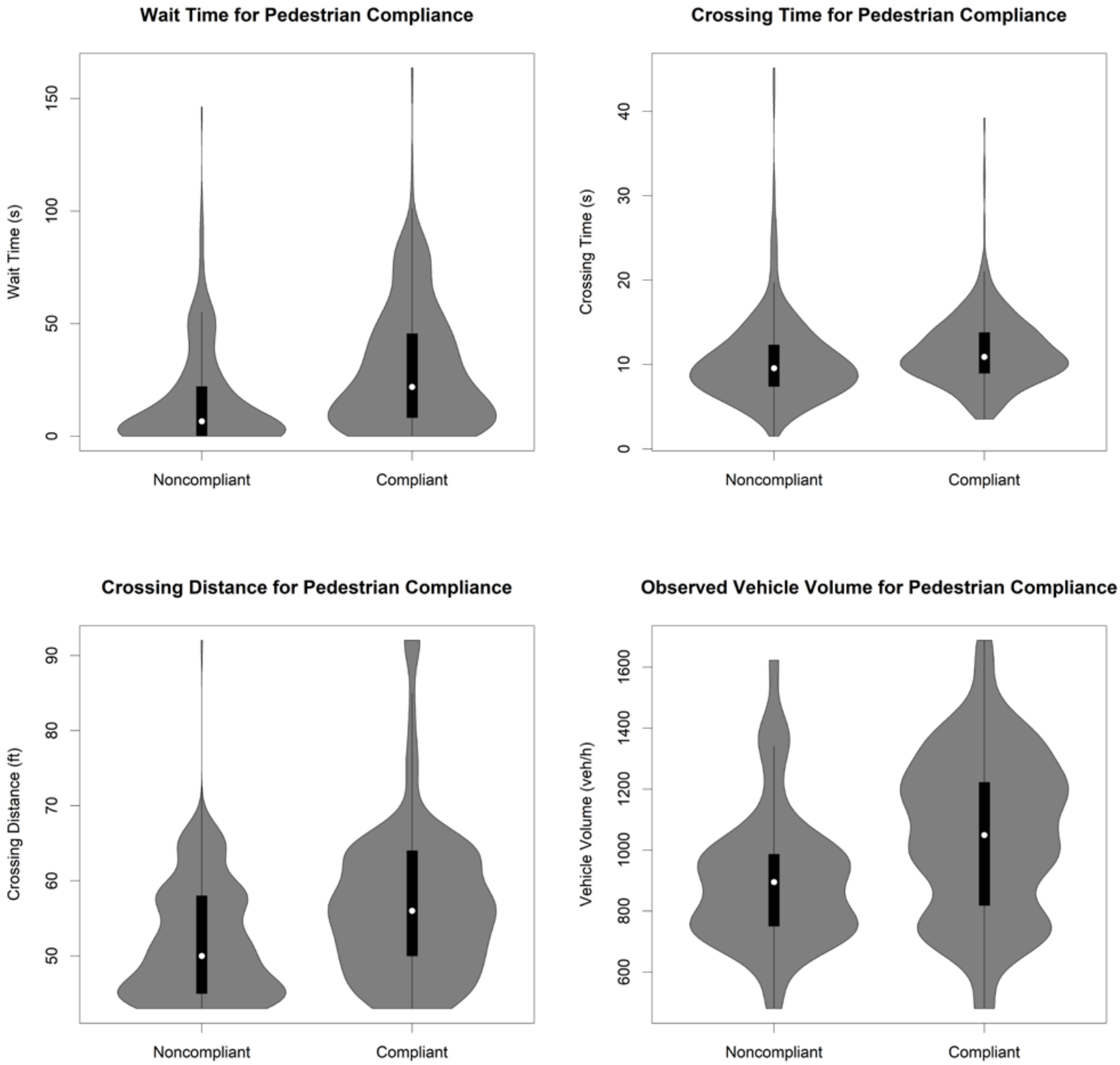

Figure 4 Violin plots of continuous variables for both compliant and noncompliant crossings.

3.2 Estimation of Conflict Models

Since each observation in the dataset was classified based on whether a conflict occurred between a pedestrian and a vehicle, only two distinct outcomes are possible. Due to this, binary logistic regression was used to analyze the data, as this type of model is suitable for estimating models with a binary response variable. The form of the binary logistic regression model is specified in Equation (1).

$$logit(\pi_i) = \log\left(\frac{\pi_i}{1-\pi_i}\right) = \beta_0 + \beta_1 X_{i,1} + \cdots + \beta_{p-1} X_{i,p-1} \quad (1)$$

Alternatively, the expression above can be simplified as shown in Equation (2):

$$\pi_i = \frac{\exp\left(\boldsymbol{X}_i'\boldsymbol{\beta}\right)}{1+\exp\left(\boldsymbol{X}_i'\boldsymbol{\beta}\right)} \quad (2)$$

Where:

- π_i is the probability of a pedestrian-vehicle conflict for each pedestrian i.
- $\boldsymbol{X}_i'$ is a vector of quantities for p covariates for each pedestrian i.
- $\boldsymbol{\beta}$ is a vector of p regression coefficients.

Due to the small number of observations in the dataset that were classified as a conflict, it is not practical to divide the data into training and validation sets. Instead of doing this, *K*-fold cross validation was used; in this case, the data were randomly split into *K* equal sized parts (i.e., folds) and a model was estimated on *K*-1 of these parts. This process was repeated *K* times such that each of the *K* folds is held out exactly one time (Hastie, 2009). In order to estimate models using *K*-fold cross validation, the *train* function from the *caret* package was used in the R programming language (Kuhn, 2008; R Core Team, 2021; RStudio Team, 2022). This function can estimate many different types of models and can natively incorporate cross validation into the model estimation process. For all models, 10 folds were used for *K*-fold cross validation.

As displayed in Table 6, only a small percentage of the data (3.2%) were categorized as minor conflicts, which could cause a standard logistic regression model to underpredict the probability of a conflict. Incorporating weights for both positive and negative events in the dataset could provide a solution to this issue and increase the predictive ability of a given model. When weights are added to a model, the weighted log-likelihood is maximized instead of the log-likelihood (Tomz et al., 2003). The weighted log-likelihood can be seen in Equation 3. The weights, which are shown in Equation 4 and Equation 5, attempt to account for the uneven distribution of events in both the minority and majority classes; in other words, these weights put more emphasis on observations that were classified as a conflict and decrease the influence of non-conflict events.

$$LL_w = w_1 \sum_{\{Y_i=1\}} \log(\pi_i) + w_0 \sum_{\{Y_i=0\}} \log(1-\pi_i) \quad (3)$$

$$w_1 = \frac{n}{2m} \quad (4)$$

$$w_0 = \frac{n}{2(\mathrm{n}-m)} \quad (5)$$

Where

LL_w is the weighted log-likelihood of a specified model.
w_1 is the weight is applied to conflict events.
w_0 is the weight applied to non-conflict events.
π_i is the probability of a pedestrian-vehicle conflict for each pedestrian i.
Y_i is a term that denotes the presence of a conflict. A value of 1 indicates that a conflict occurred, while a value of 0 indicates that a conflict did not occur.
n is the total number of observations in the dataset.
m is the total number of observations in the dataset that were classified as a conflict.

Five different quantities, which are referred to as "performance measures" in this report, were used to measure the predictive accuracy of a given model. For each of these indicators values close to 1 indicate higher predictive ability (Filipovska and Mahmassani, 2020; Olson and Delen, 2008). The performance measures are defined as follows:

True Positive Rate (TPR):

$$TPR = \frac{TP}{TP+FN} \quad (6)$$

True Negative Rate (TNR):

$$TNR = \frac{TN}{TN+FP} \quad (7)$$

Positive Predictive Value (PPV):

$$PPV = \frac{TP}{TP+FP} \quad (8)$$

Negative Predictive Value (NPV):

$$NPV = \frac{TN}{TN+FN} \quad (9)$$

Balanced Accuracy (BA)

$$BA = \frac{TPR + TNR}{2} \quad (10)$$

Where

$TP =$ the total number of true positives that a model predicted.

$TN =$ the total number of true negatives that a model predicted.

$FP =$ the total number of false positives that a model predicted.

$FN =$ the total number of false negatives that a model predicted.

3.3 Discussion of Findings for Conflict Estimation

Five different performance measures were used to determine the best performing model during the model specification stage of this analysis. Table 7 shows the performance measures for both the unmodified binary logit model (Model 1) and the weighted binary logit model (Model 2). As evident by a TPR of 0 and a TNR equal to 1, Model 1, despite multiple iterations of model specification that attempted to include each variable in the model, was unable to predict any pedestrian-vehicle conflicts. This inability to predict any positive outcomes may be due to the imbalance of conflict and non-conflict observations that are present in the dataset; since only 3.2% of the data were categorized as a conflict, a standard binary logistic regression model was unable to account for this high proportion of zero-values and drastically underpredicted the number of conflicts. Model 2 was created to potentially resolve this issue. As shown in Table 7, all of the performance measures for Model 2 are relatively high (i.e., close to 1.00) except for the PPV, which is equal to 0.112. These values indicate that this model is able to accurately predict a conflict for nearly all of the observations that were classified as a conflict, but it tends to overestimate the number of conflicts. In other words, this model generates a considerable number of false positives, which results in a low PPV.

Table 7 Performance measures and other measures of fit for Conflict Prediction Models

Measure	Model 1 Binary Logit	Model 2 Weighted Binary Logit
TPR	0.000	0.889
TNR	1.000	0.769
PPV	Undefined	0.112
NPV	0.968	0.995
BA	0.500	0.829
Null Deviance	239.40	1178.35
Residual Deviance	209.60	899.22
AIC	221.60	*na*
BIC	250.07	*na*

Note: *na* = not applicable

The coefficient estimates, standard errors, p-values, and unit change in odds for both Model 1 and Model 2 are shown in Table 8**.** Here, the Unit Change in Odds (%) column represents the change in the odds of a conflict associated with a unit increase in a given variable, assuming that all others are held constant. The change in odds was calculated using the equation $Unit\ Change\ in\ Odds\ (\%) = 100\left(e^{\beta} - 1\right)$, where e is Euler's number and β is a parameter estimate. When positive, this value indicates that a variable is positively associated with conflicts between pedestrians and vehicles. Conversely, a negative unit change in odds denotes that a variable is negatively associated with pedestrian-vehicle conflicts.

Although the usefulness of Model 1 may be constrained by its inability to predict any pedestrian vehicle conflicts, many of the coefficient estimates, displayed in Table 8, are similar in both models. In Model 1, the statistically significant variables were Crossing Time, Median, Log(Observed Vehicle Volume), October, and Concurrent or Exclusive Phasing. Here, Log(Observed Vehicle Volume) is the natural logarithm of the vehicle volume that was recorded at each intersection and Concurrent or Exclusive Phasing is a dummy variable that denotes if an intersection has either concurrent phasing with auxiliary signage, concurrent phasing without auxiliary signage, or exclusive phasing.

Since one of the objectives of this analysis was to determine the safety effects of converting an intersection from side street green to concurrent phasing, it should be noted that numerous attempts were made to include unique variables for concurrent phasing. However, none of the models were estimated that contained statistically significant terms for concurrent phasing; the only way to include a variable related to concurrent phasing was to create a dummy variable that indicates if an intersection has either concurrent or exclusive phasing. Model 1 found that concurrent or exclusive phasing, compared to side street green phasing, decreased the odds of a conflict by approximately 57.6% and the presence of a median decreased the odds of a conflict by nearly 90.7%. A unit increase in both a pedestrian's crossing and the natural logarithm of the observed vehicle volume were found to increase the odds of a conflict by 8.8% and 1,366.5%, respectively. Finally, observations recorded during the month of October were found to increase the odds of a conflict by 280.0%.

Model 2 is a binary logistic regression model that incorporates weights to account for the imbalance of conflict and non-conflict events that is present in the dataset. This model contains seven statistically significant variables, namely Wait Time, Crossing Time, Median, Log(Observed Vehicle Volume), August, November, and Concurrent or Exclusive Phasing. A unit increase in the time a pedestrian spent waiting to cross the street, the presence of a median, observations gathered in August, and observations gathered in November were found to decrease the odds of a conflict by 0.9%, 88.3%, 58.0%, and 91.4%, respectively. Only two variables in this model were found to increase the odds of pedestrian conflict; in particular, a unit increase in a pedestrian's crossing time and a unit increase in the log observed vehicle volume were found to increase the odds of a conflict by 11.3% and 3,000.2%, respectively. Similar to Model 1, Model 2 includes a variable that indicates if an intersection has either concurrent or exclusive pedestrian signal phasing, which reduces the odds of a pedestrian-vehicle conflict by nearly 48.5%.

Table 8 Coefficient estimates, standard errors, p-values, and unit change in odds for Model 1 and Model 2.

Coefficients	Model 1 – Binary Logit				Model 2 – Weighted Binary Logit			
	Estimate (β)	Standard Error	P-Value	Unit Change in Odds (%)	Estimate (β)	Standard Error	P-Value	Unit Change in Odds (%)
Intercept	-23.023	5.805	7.310E-05	*na*	-23.982	3.159	8.440E-14	*na*
Wait Time	*na*	*na*	*na*	*na*	-0.009	0.004	1.590E-02	- 0.903
Crossing Time	0.085	0.044	5.302E-02	+ 8.848	0.107	0.019	3.570E-08	+ 11.323
Median	-2.371	1.064	2.583E-02	- 90.666	-2.146	0.348	1.070E-09	- 88.308
Log(Observed Vehicle Volume)	2.685	0.827	1.160E-03	+ 1366.539	3.434	0.452	7.610E-14	+ 3000.185
August	*na*	*na*	*na*	*na*	-0.868	0.291	2.909E-03	- 58.009
October	1.335	0.439	2.340E-03	+ 280.000	*na*	*na*	*na*	*na*
November	*na*	*na*	*na*	*na*	-2.452	0.316	2.700E-14	- 91.385
Concurrent or Exclusive Phasing	-0.858	0.424	4.2888E-02	- 57.602	-0.663	0.197	7.950E-04	- 48.493

Note: *na* = not applicable

3.4 Pedestrian Compliance Models

After all of the data was gathered, each pedestrian who crossed the road was classified as being either compliant or noncompliant with the corresponding pedestrian signals. As a result of this type of classification, binary logistic regression was used to analyze the data and estimate the probability of pedestrian compliance for each person who crossed the street. The form of the binary logistic regression model used in this part of the analysis is specified in Equation (11).

$$\mathrm{logit}(\pi_i) = \log\left(\frac{\pi_i}{1-\pi_i}\right) = \beta_0 + \beta_1 X_{i,1} + \cdots + \beta_{p-1} X_{i,p-1} \quad (11)$$

Alternatively, the expression above can be simplified as shown in Equation (12):

$$\pi_i = \frac{\exp(\mathbf{X}_i'\boldsymbol{\beta})}{1+\exp(\mathbf{X}_i'\boldsymbol{\beta})} \tag{12}$$

Where:

- π_i is the probability of a pedestrian complying with the appropriate pedestrian signal for each pedestrian i.
- $\mathbf{X}_i'$ is a vector of quantities for p covariates for each pedestrian i.
- $\boldsymbol{\beta}$ is a vector of p regression coefficients.

The modeling results of the pedestrian compliance portion of this analysis can be found in Table 9. Here, the statistically significant covariates were Wait Time, Concurrent w/o Signage, Exclusive Phase, Crossing Distance, and Crosswalks. In this model, the variables Concurrent w/o Signage and Exclusive Phase are dummy variables that indicate if an intersection had concurrent phasing without auxiliary signage or exclusive phasing, respectively. A unit increase in the time a pedestrian spent waiting to cross the street and a unit increase in crossing distance were found to increase the odds of pedestrian compliance by nearly 2.7% and 8.6%, respectively. The presence of a painted crosswalk was found to dramatically increase pedestrian compliance; specifically, this variable was found to increase the odds of signal compliance by almost 102.7%. Both parameters related to the type of signal control present at an intersection were found to decrease the odds of compliance; when compared to side street green phasing, concurrent phasing without auxiliary signage and exclusive phasing were found to decrease the odds of signal compliance by nearly 45.8% and 45.3%. It should be noted that concurrent phasing with auxiliary signage was not statistically significant in this model, which, when combined with the fact that the other type of concurrent phasing was found to reduce signal compliance, suggests that auxiliary signage is needed to ensure that pedestrians legally cross the street.

Table 9 Parameter estimates, standard errors, p-values, and unit change in odds for the pedestrian compliance model.

Parameters	Estimate	Standard Error	P-Value	Unit Change in Odds (%)
Intercept	-5.010	0.680	1.720E-13	*na*
Wait Time	0.027	0.004	5.000E-13	+ 2.716
Concurrent w/o Signage	-0.612	0.279	2.841E-02	- 45.752
Exclusive Phase	-0.604	0.172	4.460E-04	- 45.322
Crossing Distance	0.083	0.011	3.310E-13	+ 8.640
Crosswalks	0.707	0.236	2.727E-03	+ 102.699
Null Deviance	1154.90			
Residual Deviance	1004.30			

AIC	1016.30
BIC	1044.79

Note: *na* = not applicable

To illustrate the effects of each type of pedestrian signal on the probability of compliance, *k*-means clustering in the R programming environment was used to create six prototypical crossing conditions based on the data that were collected in this study (MacQueen, 1967; R Core Team, 2021; RStudio Team, 2022). The coefficients from the model presented in Table 9 were used to estimate the probability of pedestrian compliance at each of these six conditions. The estimated probability of compliance at each type of signal and the values that were used to estimate this percentage can be seen in Table 10.

Table 10 Estimated pedestrian compliance using the coefficients from the pedestrian compliance model.

Prototype Crossing Conditions	Wait Time (s)	Crossing Distance (ft)	Crosswalk Presence	Pedestrian Compliance by Phasing Type (%)			
				Side Street Green	Concurrent w/ Signage	Concurrent w/o Signage	Exclusive
1	24.29	73.08	No	84.52	84.52	74.76	74.91
2	49.22	53.31	No	67.41	67.41	52.88	53.07
3	23.23	50.69	Yes	62.72	62.72	47.71	47.91
4	85.01	58.76	Yes	94.50	94.50	90.32	90.39
5	5.28	59.72	No	52.03	52.03	37.04	37.23
6	3.37	47.40	Yes	42.94	42.94	28.99	29.15

Since no variables unique to intersections with concurrent phasing with auxiliary signage were included in the compliance model, shown in Table 9, all of the example conditions in Table 10 have the same probability of compliance for both side street green and concurrent phasing with signage. However, both concurrent without signage and exclusive phasing were found to have significantly lower probabilities of compliance for all of the prototypical conditions; This finding indicates that auxiliary signage may be needed to improve pedestrian compliance at concurrent phase intersections; if signage is not present, concurrent phase intersections have a similar probability of compliance as intersections with exclusive pedestrian signal phasing.

It is possible this unexpected finding may be due to the newness of concurrent operation. It is noteworthy that a concurrent phase intersection without signage would look identical to an exclusive phase signal, and there was no significant difference in the compliance between these two operations. The auxiliary signage would indicate to pedestrians that they will not have to wait for all traffic to stop before they get the walk signal. It is also possible that the signage alerted pedestrians to the fact that this was a new signal installation that they may have learned about in the educational campaign.

CHAPTER 4 CONCLUSIONS, RECOMMENDATIONS AND SUGGESTED RESEARCH

4.1 Summary of Research

This report describes research investigating the safety effects of converting the pedestrian signal operation at several intersections from side street green to concurrent phasing. First, groups of intersections operating under side street green pedestrian signal phasing were selected with similar characteristics, such as crossing width, the number of vehicle lanes, AADT, and the presence of pedestrian infrastructure. An intersection with exclusive phasing and similar characteristics was also added to each group. Data related to individual pedestrian crossing experiences, the type of pedestrian-vehicle interaction, vehicular volumes, and signal compliance were collected at each of the selected intersections in the before period. Next, two of the three side street green intersections in each group were designated for conversion to concurrent phasing; one with auxiliary signage, and the other without. Physical installation of each treatment began in April 2022 and ended in September of the same year. Subsequently, data were collected in the after period following the same guidelines as the before data.

Weighted binary logistic regression was used to predict the probability of a conflict for each pedestrian that crossed the road as a function of both intersection characteristics and pedestrian behavior, such as wait time and crossing time. No pedestrian vehicle conflicts were recorded at any of the intersections with concurrent phasing in the after period. In addition to this, intersections with either concurrent or exclusive phasing, compared to sites with side street green phasing, were found to decrease the odds of a conflict by over 48%. Other variables that were found to reduce the probability of a conflict were a pedestrian's waiting time and the presence of a median.

Following a procedure similar to the conflict analysis, binary logistic regression was also used to estimate the probability of pedestrian compliance for each person that crossed the street. In this model, the significant covariates are waiting time, concurrent phasing without signage, exclusive phasing, crossing distance, and the presence of crosswalks. To demonstrate the effects of each type of pedestrian signal on pedestrian compliance, *k*-means clustering was used to created six prototypical intersections based on the data that were gathered in this study. Using the characteristics of these example intersections and the coefficient estimates from the pedestrian compliance model, the probability of compliance was estimated four times for each intersection, such that each intersection was treated as if it operated under one of the four types of pedestrian signal phasing.

4.2 Recommendations

Based on the observations of pedestrian crossing behaviors and the potential for pedestrian-vehicle conflict at intersections with exclusive, side street green, and concurrent pedestrian signal phasing, it is the project team's recommendation that CTDOT considers converting all side street green signals to concurrent phasing. Investigation into the conversion of all remaining intersections operating under exclusive pedestrian phasing to concurrent phasing signals is also recommended. Priority for such conversion should consider local conditions at each signal, including intensity of pedestrian activity, high levels of use of the intersection by school children and senior or disabled pedestrians, the relative volume of turning vehicles on the side street, and running speed of traffic on the main road.

The presence of a median appeared to help lessen conflicts tremendously and could be considered in locations without one, where feasible. Also, previous research has found that marked crosswalks and the presence of sidewalks also help lessen the odds of a pedestrian and vehicle conflict, although these were not found to influence the odds of a conflict in this study.

Observations recorded during the month of October were found to increase the odds of a conflict by 280.0%, while the odds of a conflict decreased by 58% and 91% during August and November, respectively. State crash data from the CT Crash Data Repository[2] reveals October has a higher proportion of crashes involving non-motorists compared to other months. Environmental changes (i.e., inclement weather) or changes in social/behavioral patterns during this period may explain the increased odds of a conflict. Consequently, increased pedestrian safety messaging during this month may be advantageous.

4.3 Suggested Research

The research findings lead to several suggested future research directions.

Safety effectiveness evaluation helps assess the change in pedestrian related crashes after converting side street green signals to concurrent phasing, which is also known as the estimation of Crash Adjustment Factors (CAFs). Although pedestrian related crashes can be collected for the before period at those intersections that have side street green signals converted, crashes for the after period are not readily available within a short time period, considering the fact that pedestrian crashes are generally rare. Follow-up research is suggested to evaluate the pedestrian crash reduction at those intersections that have side street green signals converted to concurrent phasing, when crash samples are enough for the before-after study. The safety effectiveness evaluation will further help justify whether converting side street green signals to concurrent phasing significantly improves pedestrian safety at signalized intersections.

Engineering economic analysis (EEA) helps conduct the economic justification of converting side street green signals to concurrent phasing, by comparing the costs of new signal installation with the potential benefits to be received through crash reduction. EEA also helps prioritize intersections for pedestrian signal conversion to optimize traffic flow and improve pedestrian safety when there is a budget limitation. Future research on EEA can help CTDOT

[2] CT Crash Data Repository can be accessed here http://www.ctcrash.uconn.edu

better allocate budget for intersection safety improvement, when converting side street green signals to concurrent phasing for all intersections across the State is not economically feasible due to the limited budget.

Exclusive pedestrian phasing requires adding an additional signal phase every time a pedestrian pushes the call button, while concurrent phasing simply extends the length of the side road phase to provide enough time for pedestrians to cross the main road safely. Having the additional phase in the cycle compromises efficient signal operation by disrupting signal coordination along a corridor and substantially increasing delay for all road users. Past research by the lead PI has also found that pedestrians are less likely to wait for the walk signal at exclusive phase intersections and that pedestrian crashes at signals with exclusive pedestrian phasing are significantly more severe than at signals with side street green pedestrian phasing (Zhang et al. 2015). Converting intersections in the state from exclusive to concurrent pedestrian phasing has the potential to substantially reduce delay along with reducing pedestrian casualties. It would be beneficial to conduct research using a properly executed effectiveness of treatment study design to confirm whether comprehensive conversion of exclusive phase signals to concurrent phasing could indeed improve operational efficiency and safety at the same time. As noted above, such research should evaluate how the safety effectiveness might vary by local conditions at each signal, including intensity of pedestrian activity, high levels of use of the intersection by school children and senior or disabled pedestrians, the relative volume of turning vehicles on the side street, and running speed of traffic on the main road.

CHAPTER 5 IMPLEMENTATION OF RESEARCH RESULTS

Following is a possible plan for implementing the research results and recommendations.

1. Identify remaining intersections with side street green phasing.
2. Complete a safety analysis to determine which installations should be considered first.
3. Conduct research as suggested in chapter 4.
4. Develop an installation schedule for conversion of side street green and/or exclusive phase signals to concurrent operation.
5. Carry out an educational campaign to announce conversion of phasing along with detailed information about how to use the signals.
6. Conduct educational campaigns and other things to encourage public adoption.
7. Conduct follow up study to document effectiveness.

REFERENCES

Filipovska, Monika; Hani S. Mahmassani. 2020. “Traffic Flow Breakdown Prediction Using Machine Learning Approaches.” *Transportation Research Record*, vol. 2674, no. 10, p. 560–70.

Hastie, Trevor; Tibshirani, Robert; Friedman, Jerome. 2009. “Model Assessment and Selection.” *The Elements of Statistical Learning: Data Mining, Inference, and Prediction*, Springer, 2009, pp. 219–61.

Kuhn, Max. 2008. “Building Predictive Models in R Using the Caret Package.” *Journal of Statistical Software*, vol. 28, Nov. 2008, pp. 1–26.

Laureshyn, Aliaksei; András Várhelyi. 2018. *The Swedish Traffic Conflict Technique: observer’s manual*, Lund University, Sweden.

MacQueen, J. 1967. “Classification and analysis of multivariate observations.” *5th Berkeley Symp. Math. Statist. Probability*. Los Angeles LA USA: University of California.

Olson, David L.; Dursun Delen. 2008. “Performance Evaluation for Predictive Modeling.” *Advanced Data Mining Techniques*, edited by David L. Olson and Dursun Delen, Springer.

R Core Team. 2021. *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing, https://www.R-project.org/.

RStudio Team. 2022. RStudio: Integrated Development for R. *RStudio, PBC*, Boston, MA. http://www.rstudio.com/

Tomz, Michael; King, Gary; Zeng, Langche. 2003. “ReLogit: Rare Events Logistic Regression.” *Journal of Statistical Software*, vol. 8, pp. 1–27.

Zhang, Yaohua; Mamun, Sha al; Ivan, John N.; Ravishanker, Nalini; Haque, Khademul. 2015. “Safety effects of exclusive and concurrent signal phasing for pedestrian Crossing.” *Accident Analysis and Prevention*, Vol. 83, p. 26–36.

APPENDIX A SURVEY QUESTIONS

Crossing Behaviors

1. What state do you live in?
    a. Connecticut
    b. Other
2. How often do you, as a pedestrian, cross roads with high traffic volume?
    a. Never
    b. Rarely
    c. Sometimes
    d. Always
3. When walking, how often do you cross the street at locations other than intersections and crosswalks (i.e. middle of a block, unmarked areas, etc.)?
    a. Never
    b. Rarely
    c. Sometimes
    d. Always
4. When crossing the street at an intersection or crosswalk with a pedestrian signal, how often do you cross during the "don't walk" phase?
    a. Always
    b. Sometimes
    c. Rarely
    d. Never
5. When walking on a road with a sidewalk, how often do you walk on the road instead of the sidewalk?
    a. Never
    b. Rarely
    c. Sometimes
    d. Always
6. How often do you cross the road without watching for cars?
    a. Always
    b. Sometimes
    c. Rarely
    d. Never
7. How often do you <u>run</u> while crossing the road?
    a. Never
    b. Rarely
    c. Sometimes
    d. Always
8. Compared to other pedestrians, what is the probability that you will be involved in an accident while crossing the street?
    a. Much lower probability

b. Lower probability
c. Same probability
d. Higher probability
e. Much higher probability

Normative Beliefs

9. How much do each of the following factors affect your road crossing choices as a pedestrian? (See Appendix B for full list of response choices)
10. Please indicate your level of agreement or disagreement with the following statements. (Response choices: *Strongly Agree, Agree, Neither Agree nor Disagree, Disagree, Strongly Disagree*)
    a. I often have to wait too long to cross the street at intersections and crosswalks with pedestrian signals.
    b. Having an exclusive phase for pedestrians (i.e., cars from all directions are stopped while pedestrians walk) at intersections makes me feel safer.
    c. Having an exclusive phase for pedestrians (i.e., cars for all directions are stopped while pedestrians walk) at intersections makes it easier for me to get where I need to go.
    d. When walking, I trust drivers to respect my rights as a pedestrian.
11. Please indicate your level of agreement or disagreement with the following statements. (Response choices: *Strongly Agree, Agree, Neither Agree nor Disagree, Disagree, Strongly Disagree*)
    a. Traffic laws should be obeyed, regardless of whether they seem logical.
    b. It is sometimes alright to cross the road with a "don't walk" signal, if one makes sure that there is no traffic in the area.
    c. Walk signals are mainly intended for children, elderly people, and disabled people.
    d. I wait for a "walk" sign because I believe that it is important to comply with the law.
    e. I wait for a "walk" sign because I believe that road safety laws protect pedestrians.
12. How often do you currently use each of the following modes of transportation? (Response choices: *Every day, A few times a week, A few times a month, Once a month or less, Never*)
    a. Driving
    b. Walking
    c. Cycling
    d. Public Transit

Opinions on Educational Material

13. How familiar are you with the following pedestrian signals? (Response choices: *Not familiar at all, Slightly familiar, Moderately familiar, Very familiar, Extremely familiar).*
    a. Exclusive Phasing Pedestrian Signal
    b. Side Street Green Pedestrian Signal
    c. Concurrent Phasing Pedestrian Signal
14. The following 3 images are a part of one brochure. Please view the 3 images and respond to the following questions about the brochure as a whole (See Figure 1 above).
15. Please indicate your level of agreement with the following statements:
    a. The brochure above is.... *Response choices: Strongly Agree, Agree, Neither Agree nor Disagree, Disagree, Strongly Disagree
        i. Clear
        ii. Easy to Understand
        iii. Informative
        iv. Visually Appealing
16. Tell us in a few words what the brochure is about. (open text box)
17. What did you like about the brochure? (open text box)
18. What could be improved about the brochure? (open text box)

Demographics

19. What is your age?
    a. Under 18
    b. 18 - 24
    c. 25 - 34
    d. 35 - 44
    e. 45 - 54
    f. 55 - 64
    g. 65 - 74
    h. 75 - 84
    i. 85 or older
20. What is your gender?
    a. Female
    b. Male
    c. Non-binary/Non-conforming
    d. Other
    e. Prefer not to answer
21. Are you of Hispanic, Latinx or Spanish origin?
    a. Yes
    b. No

22. How do you identify?
    a. White
    b. Black or African American
    c. American Indian or Alaskan Native
    d. Asian or Asian American
    e. Native Hawaiian or Pacific Islander
    f. Other________________
23. What is your total household income?
    a. Less than $25,000
    b. $25,000 to $49,999
    c. $50,000 to $74,999
    d. $75,000 to $99,999
    e. $100,000 to $149,999
    f. $150,000 or More
    g. Prefer not to say
24. What is the highest level of education you have completed?
    a. Some high school
    b. High school or equivalent (GED)
    c. Associate’s degree
    d. Bachelor's degree
    e. Master's degree
    f. Ph.D. or other terminal degree
    g. Trade school
    h. Other

APPENDIX B DESCRIPTIVE STATISTICS OF ADDITIONAL SURVEY QUESTIONS

How much do each of the following factors affect your road crossing choices as a pedestrian?	Greatly increases likelihood of crossing during "don't walk" phase N (Row %)	Increases likelihood of crossing during "don't walk" phase N (Row %)	Does not affect my behavior N (Row %)	Increases likelihood of crossing during "walk" phase N (Row %)	Greatly increases likelihood of crossing during "walk" phase N (Row %)
High traffic volume	62 (14.50)	18 (4.2)	85 (19.9)	60 (14.0)	203 (47.4)
No Traffic	110 (25.7)	114 (26.6)	131 (30.6)	42 (9.8)	31 (7.2)
Darkness	24 (5.6)	33 (7.7)	131 (30.6)	88 (20.6)	152 (35.5)
Bad weather	35 (8.2)	44 (10.3)	102 (23.8)	98 (22.9)	149 (34.8)
Long duration of "don't walk sign"	49 (11.4)	109 (25.5)	154 (36.0)	63 (14.7)	53 (12.4)
Presence of other pedestrians who cross with a "don't walk" sign	46 (10.7)	107 (25.0)	179 (41.8)	59 (13.8)	37 (8.6)
Presence of other pedestrians who cross with a "walk" sign	32 (75)	30 (7.0)	161 (37.6)	101 (23.6)	104 (24.3)
No other pedestrians present	32 (7.5)	47 (11.0)	233 (54.4)	66 (15.4)	50 (11.7)
Walking with a child	26 (6.1)	25 (5.8)	104 (24.3)	57 (13.3)	216 (50.5)
Walking with a familiar person	22 (55.1)	35 (8.2)	171 (40.0)	97 (22.7)	103 (24.1)

Question	Strongly Disagree N (Row %)	Disagree N (Row %)	Neither Agree nor Disagree N (Row %)	Agree N (Row %)	Strongly Agree N (Row %)
I often have to wait too long to cross the street at intersections and crosswalks with pedestrian signals	47 (11.0)	104 (24.3)	118 (27.6)	116 (27.1)	43 (10.0)
Having an exclusive phase for pedestrians (i.e. cars from all directions are stopped while pedestrians walk) at intersections makes me feel safer.	19 (4.4)	31 (7.2)	84 (19.6)	164 (38.3)	130 (30.4)
Having an exclusive phase for pedestrians (i.e. cars for all directions are stopped while pedestrians walk) at intersections makes it easier for me to get where I need to go.	21 (4.9)	29 (6.8)	101 (23.6)	150 (35.0)	127 (29.7)
When walking, I trust drivers to respect my rights as a pedestrian.	81 (18.9)	103 (24.1)	92 (21.5)	105 (24.5)	47 (11.0)
Traffic laws should be obeyed, regardless of whether they seem logical	24 (5.6)	31 (7.2)	68 (15.9)	169 (39.5)	136 (31.8)
It is sometimes alright to cross the road with a "don't walk" signal, if one makes sure that there is no traffic in the area.	52 (12.1)	76 (17.8)	27 (29.7)	141 (32.9)	32 (7.5)
Walk signals are mainly intended for children, elderly people, and disabled people.	150 (35.0)	111 (25.9)	75 (17.5)	54 (12.6)	38 (8.9)
I wait for a "walk" sign because I believe that it is important to comply with the law.	29 (6.8)	60 (14.0)	125 (29.2)	137 (32.0)	77 (18.0)
I wait for a "walk" sign because I believe that road safety laws protect pedestrians.	30 (7.0)	55 (12.9)	84 (19.6)	153 (35.7)	106 (24.8)