A Driving Simulator Evaluation of Red Arrows and Flashing Yellow Arrows in Right-Turn Applications

Establishing the Foundation for Future Research

SAFER SIM

SAFETY RESEARCH USING SIMULATION

UNIVERSITY TRANSPORTATION CENTER

Michael Knodler
Associate Professor
Civil and Environmental Engineering
University of Massachusetts Amherst

David A. Noyce
Director and Chair
Traffic Operations and Safety Laboratory
Department of Civil and Environmental Engineering
University of Wisconsin-Madison

A Driving Simulator Evaluation of Red Arrows and Flashing Yellow Arrows in Right-Turn Applications: Establishing the Foundation for Future Research

Michael Knodler
Associate Professor
Civil and Environmental Engineering
University of Massachusetts Amherst

David A. Noyce
Director and Chair
Traffic Operations and Safety Laboratory
Department of Civil and Environmental Engineering
University of Wisconsin-Madison

Elizabeth Casola
Graduate Research Assistant
Civil and Environmental Engineering
University of Massachusetts Amherst

Kelvin R. Santiago
Assistant Researcher
Traffic Operations and Safety Laboratory
Department of Civil and Environmental Engineering
University of Wisconsin-Madison

Andrea R. Bill
Associate Researcher
Traffic Operations and Safety Laboratory
Department of Civil and Environmental Engineering
University of Wisconsin-Madison

Madhav V. Chitturi
Assistant Scientist
Traffic Operations and Safety Laboratory
Department of Civil and Environmental Engineering
University of Wisconsin-Madison

A Report on Research Sponsored by SAFER-SIM

November 2017

Table of Contents

List of Figures

List of Tables

Abstract

Driver understanding of flashing yellow arrow (FYA) indications for left turns has been studied extensively; however, the use of FYA for right-turn applications is an area that needs to be better understood through evaluations focused on actual driver behavior. Field evaluations, surveys, and driving simulator experiments are some alternatives for studying drivers' comprehension of and reactions to signal indications such as a right-turn FYA. Among the alternatives, field evaluations have the advantage of providing insight into the behavior of drivers in a real-life environment, and survey-based evaluations have the advantage of providing insight into how drivers comprehend a new signal indication. Driving simulators provide an experimental environment for conducting fine-grained safety evaluations.

Survey-based and field-based evaluations provide a foundation that is key to conducting future FYA research that involves driving simulators. When preparing to conduct a simulator evaluation, a clearly defined set of research questions is needed since the number of subjects and scenarios that can be studied is limited. Therefore, the research presented establishes a foundation for a future study of how an FYA indication is understood by drivers when used in a right-turn application. The foundation is established using a survey-based evaluation and a field-based evaluation aimed at better understanding how drivers react to FYA indications on right turns.

The FYA for right-turn applications and a dynamic no-turn-on-red sign were evaluated using a computer-based static survey evaluation to determine whether drivers grasp the message of the devices. The study evaluated the results from 200 respondents based on the existing passive green and red phase conditions, the proposed right FYA, and a dynamic no-turn-on-red sign. Results indicate that drivers have a strong comprehension of the FYA and dynamic no-turn-on-red messages. There was a significant statistical difference in responses in terms of the increase in the response designating the action of yielding as approaching the intersection from the existing condition to the FYA.

As part of a field-based evaluation, vehicle-pedestrian interactions were documented on sites with and without an FYA indication on the right turn as well as on a site with an FYA indication on the right turn. Documentation of the interactions was achieved using a frame-by-frame analysis of video recordings from the sites. A model explaining the deviation of a driver from an expected right-turn behavior as a result of the presence of a pedestrian was created. The model takes into consideration the position of a pedestrian within the crosswalk as well as the presence of an FYA indication on the right turn. The feasibility of creating the model demonstrates the possibility of assessing the quality of a future driving simulator experiment on the application of FYA for right turns.

1 Introduction

Research performed by the National Highway Traffic Safety Administration (NHTSA) studied how crashes at controlled intersections were attributed to inattention, illegal maneuvers, or false assumptions about other users' actions [1]. Due to the variety of turning movements that can be performed at signalized intersections, the vulnerability of pedestrians becomes more apparent upon entering a crosswalk. According to a report from NHTSA in 2015, there were 5,376 pedestrian fatalities related to traffic crashes, a 9.5% increase since 2014 [2]. Various applications have been utilized to communicate a permissive turn to drivers. Many researchers, including the National Cooperative Highway Research Program, concluded that the use of the flashing yellow arrow (FYA) is a more effective and safer indication for permissive turns than the circular green light [3].

Flashing yellow arrows on left turns have the distinct advantage of reinforcing the message to drivers that they need to wait for a gap in the opposing traffic stream before crossing. Therefore, the FYA concept has been expanded to right-turn applications. One premise for the use of a right-turn FYA is that the indication will reinforce the message that drivers need to yield to conflicting pedestrians. Driver understanding of FYA indications on left turns has been studied extensively; however, the use of FYA for right-turn applications is an area that needs to be better understood through evaluations focused on actual driver behavior. Field evaluations, surveys, and driving simulator experiments are some alternatives for studying the reaction or comprehension of drivers to signal indications such as a right-turn FYA. Among the alternatives, field evaluations have the advantage of providing insight into the behavior of drivers in a real-life environment, and survey-based evaluations have the advantage of obtaining insight into how drivers comprehend a new signal indication.

Both survey-based and field-based evaluations provide a foundation that is key to conducting future research that involves driving simulators. The need for a strong foundation prior to conducting a simulator-based evaluation should not be overlooked. When preparing to conduct a simulator evaluation, a clearly defined set of research questions is needed since the number of subjects and scenarios that can be studied is limited. Therefore, the research presented here establishes a foundation for a future study of how an FYA indication is understood by drivers when used in a right-turn application. The foundation is established using a survey-based evaluation and a field-based evaluation aimed at better understanding how drivers react to FYA indications on right turns. The research presented is a collaborative effort between the University of Massachusetts-Amherst (UMass-Amherst) and the University of Wisconsin-Madison (UW-Madison). UMass-Amherst conducted the survey-based evaluation, and UW-Madison conducted the field-based evaluation. The objectives associated with each of the evaluations presented are outlined in the following sections.

1.1 Research Objectives and Goals: Survey-Based Evaluation

The first objective of the survey-based evaluation is to analyze the driver's understanding of scenarios that have a right-turn application of an FYA during the permissive phase in comparison to the existing conditions. The existing conditions consist of the traffic signal displaying a circular green indication while pedestrians and cyclists have the ability to cross the parallel crosswalk. It is hypothesized that the utilization of the right FYA will increase the yielding compliance of vehicles turning right as they enter the intersection. The use of a flashing arrow is intended to increase the vigilance of drivers towards the direction of the crosswalk. The yellow signal is intended to provide the yielding or warning message as drivers approach the intersection.

The second objective of the survey-based evaluations is evaluating the comprehension of right-turn-on-red (RTOR) restrictions during the red phase. In the state of Massachusetts, RTOR is permitted unless otherwise noted by the existing condition R10-11 "No Turn on Red" sign. The introduction of a dynamic no-turn-on-red sign utilizes the features of a variable message sign to display the no-turn-on-red information similar to the R10-11 sign with the capability to activate the message when conflicting with the phase for pedestrians. The first hypothesis is that drivers will have a strong comprehension of this new sign, therefore reducing driver confusion at the intersection. The second hypothesis is that the dynamic no-turn-on-red sign will decrease potential conflicts with pedestrians. A conflict is defined as a pedestrian being unable to cross due to the following: vehicles turning on red, a vehicle encroaching on a crosswalk while pedestrians are crossing or about to cross, and a vehicle having to suddenly brake or a pedestrian having to alter his or her path to avoid a collision.

1.2 Research Objectives and Goals: Field-Based Evaluation

The objective of the field-based evaluation is to establish a foundation for an analysis framework that can be used to answer questions about how drivers understand the message conveyed by the use of FYA on right turns when there is pedestrian presence within or next to a crosswalk. The objective is achieved using a two-step approach: first, by assembling a dataset of driver behavior observations obtained by processing video recordings; and second, by evaluating the data collected using statistical analysis techniques. In order to understand driver behavior, video cameras were installed at control intersections in the City of Madison that don't display an FYA indication for the right turn. Using frame-by-frame video-based data reduction techniques, the interactions of right-turning vehicles and pedestrians were documented.

The same video-based data reduction process was then used on a non-control site with an FYA indication on the right turn. The behavior of vehicles (expressed as a deviation from an expected value) was modeled as a function of the percentage of the crossing completed by the pedestrians when a vehicle arrived at the stop bar. Different regression models were then compared to explain the driver behavior observed. The analysis framework foundation established will support future research, including expanded research that relies on driving simulator experiments.

1.3 Report Structure

Background information on the FYA concept for right-turn applications is presented in the following sections. The research methods and results for both the survey- and field-based evaluations are presented as independent chapters. A discussion summarizing the findings and future work opportunities identified are then presented. Finally, conclusions and lessons learned from the research project are discussed.

2 Background

While technology is developing, so are the devices we plan to use that could increase levels of safety. The application of FYA indications on right turns may have an impact on how drivers and pedestrians navigate signalized intersections. Many research studies have been conducted to investigate and analyze driver behavior under several conditions. Various traffic control devices and pedestrian scenarios have been evaluated, which will help develop a platform for analyzing current driving conditions; these scenarios will be discussed further in the subsequent sections.

2.1 Right Turns at Signalized Intersections

A driver who is making a right turn at a traffic signal would typically observe his or her surroundings before completing the maneuver. As this may be intuitive for drivers, they might not be looking in full at what is there. An experiment conducted by Simons and Chabris evaluated their concept of "inattentional blindness," which suggests that we perceive objects that we focus on and could miss or not remember objects that were not part of that initial attention. Results conclude that users are more inclined to notice an unexpected object if it is similar to the object of the initial focus [4]. This study confirms the worry about pedestrian and cyclist safety while vehicles are making a right turn. Therefore, if drivers are scanning their surroundings for conflicting vehicles ahead and to the left in the intersection, there is a higher chance that they may not notice pedestrians or cyclists at crosswalks as they are not the object of the focused attention. To further this perception, Summala et al. investigated the location of drivers' attention prior to making a right turn; they concluded that drivers more frequently focused on the left leg of an intersection as the vehicles coming from the right did not seem to pose a threat to the driver. This research determines the presence of selective attention, which establishes a scanning trend where drivers concentrate their attention to detect frequent and major dangers while overlooking signs of a minor or less-frequent danger [5].

2.2 Right Turn on Red

In the states of New York, Ohio, and Wisconsin, a study observed pedestrian and bicycle crashes with right-turning vehicles for 12 months prior to and following the adoption of the RTOR. It was determined that crashes involving pedestrians increased from 1.47% to 2.28%, and those involving bicyclists increased from 1.40% to 2.79% [6]. Due to much debate over the practicality of the RTOR, the Institute of Transportation Engineers established the ITE Technical Council Committee 4M-20 to investigate driver behavior at 50 RTOR locations across five states. After collecting field data, this committee established that RTOR maneuvers made up 39.2% of all right-turn movements and, furthermore, that 95% of drivers who had the chance to turn right on red did so. Of those drivers making the RTOR, 40.4% did not come to a complete stop at the stop line or did not stop at all before entering the intersection [7].

2.3 Flashing Yellow Arrows

The *Manual on Uniform Traffic Control Devices* (MUTCD) states that the FYA indication is used to relay the message for drivers to cautiously approach and enter the intersection before making the movement displayed by the arrow. The regulations also state that the permissive FYA sharing a signal face must only have one other circular signal (steady red, steady yellow, or steady green) displayed at the same time [8]. The yellow arrow signal provides drivers with a warning message to observe surroundings prior to performing the intended maneuver. A study performed by Tipples at the University of York evaluated the use of arrows as they impact the focus of our vision. This test flashed one-direction arrows on a screen followed by an object that was not subject to follow the direction of the arrow and observed the reaction time to determine the location of the object. Results showed that reaction time was longer when the object was not located in the direction in which the arrows pointed. This demonstrates how the presence of a flashing arrow cues our attention and automatically orients our gaze to the provided direction [9]. The use of the arrow aligns the driver's gaze toward possible obstructions, including vehicles, pedestrians, and cyclists. Extensive research through the National Cooperative Highway Research Program (NCHRP) evaluated the use of the FYA as a permissive left-turn indication through the use of survey, field study, crash analysis, and implementation studies, which proved this device was as safe and well comprehended as the current permissive indications in the MUTCD. Researchers concluded that an FYA for the left-turn application was the best alternative to the circular green and was easily understood [3].

2.4 Pedestrian Safety at Controlled Intersections

Laws state that when a vehicle is facing a circular green preparing to turn right or facing a circular red preparing to turn right after completely stopping, the driver must yield the right of way to pedestrians lawfully within the intersection of the adjacent crosswalk during that signal phase [10]. During a pedestrian-crossing phase, pedestrians crossing concurrent to traffic at a four-leg intersection can have up to three possible conflicts from turning vehicles. These conflicts occur from vehicles making a right turn on green, a left turn on green, and a right turn on red. Hubbard et al. define the pedestrian conflict as the crossing being compromised, resulting in the delay of the pedestrian, the pedestrian having to alter travel path, or the pedestrian having to alter travel speed in response to the right-turning vehicle. While recording 13 intersections over 76 hours, Hubbard et al. discovered that 13.8% of pedestrians experienced a compromised crossing path. Of all the vehicles observed during this time frame, there was an average right-turn volume of 3.6 vehicles to pass during the pedestrian signal [11].

3 Research Methods: Static Survey Evaluation

An experimental design was developed as a result of reviewing previous literature and research. The objective was to investigate driver comprehension, vigilance, and situational understanding between existing and proposed intersection conditions. The following section explains the tasks that were executed to test these research objectives.

3.1 Survey Design

The static evaluation designed for this study was developed using Survey Monkey. The survey was divided into two sections: introduction/demographics and scenarios in question. The introduction included a brief description reading, "Thank you for agreeing to take this survey. The objective of our study is to observe the behavior and understanding of drivers turning right at a signalized intersection. While this survey is anonymous, you will be asked to provide some non-identifiable demographic information. The responses collected from this survey will be reviewed and analyzed only by members of our research team." It also included a participation agreement. Next, various demographic questions were asked, such as age range (18-24, 25-34, 35-44, 45-54, 55-64, and 65+), gender, and driving experience (less than 5 years, 5-9 years, and more than 10 years). The final section presented the nine traffic control device scenarios as seen in

Table 3.1.

Table 3.1 Nine survey scenarios in question

Condition	Right-Turn Permissive Display	Pedestrian Present
Existing	Circular Green Ball	Yes
		No
	Circular Red Ball	Yes
		No
	R10-11 "No Turn on Red" Sign	No
Proposed	Right Flashing Yellow Arrow	Yes
		No
	Activated Dynamic No Turn on Red Sign	No
	Deactivated Dynamic No Turn on Red Sign	No

3.2 Scenario Development

These nine scenarios were represented by their corresponding images. In addition to the signals, the R10-11 sign and the Dynamic No Turn on Red images were accessed from the Federal Highway Administration [12] and, like the signals, were placed on an intersection backdrop. The intersection portrayed in the scenarios consists of a parallel and an adjacent crosswalk as well as two thru lanes. The location used for reference was pictured at the intersection of Massachusetts Route 9 and University Drive heading west on Route 9 in Amherst, MA. A snapshot was taken at this location from the point of view of a vehicle approaching the stop bar at a time with little traffic to prevent external distraction. A second picture was captured with a pedestrian crossing the parallel crosswalk for additional signal and sign scenarios. The compiled survey images are represented in Figure 3.1.

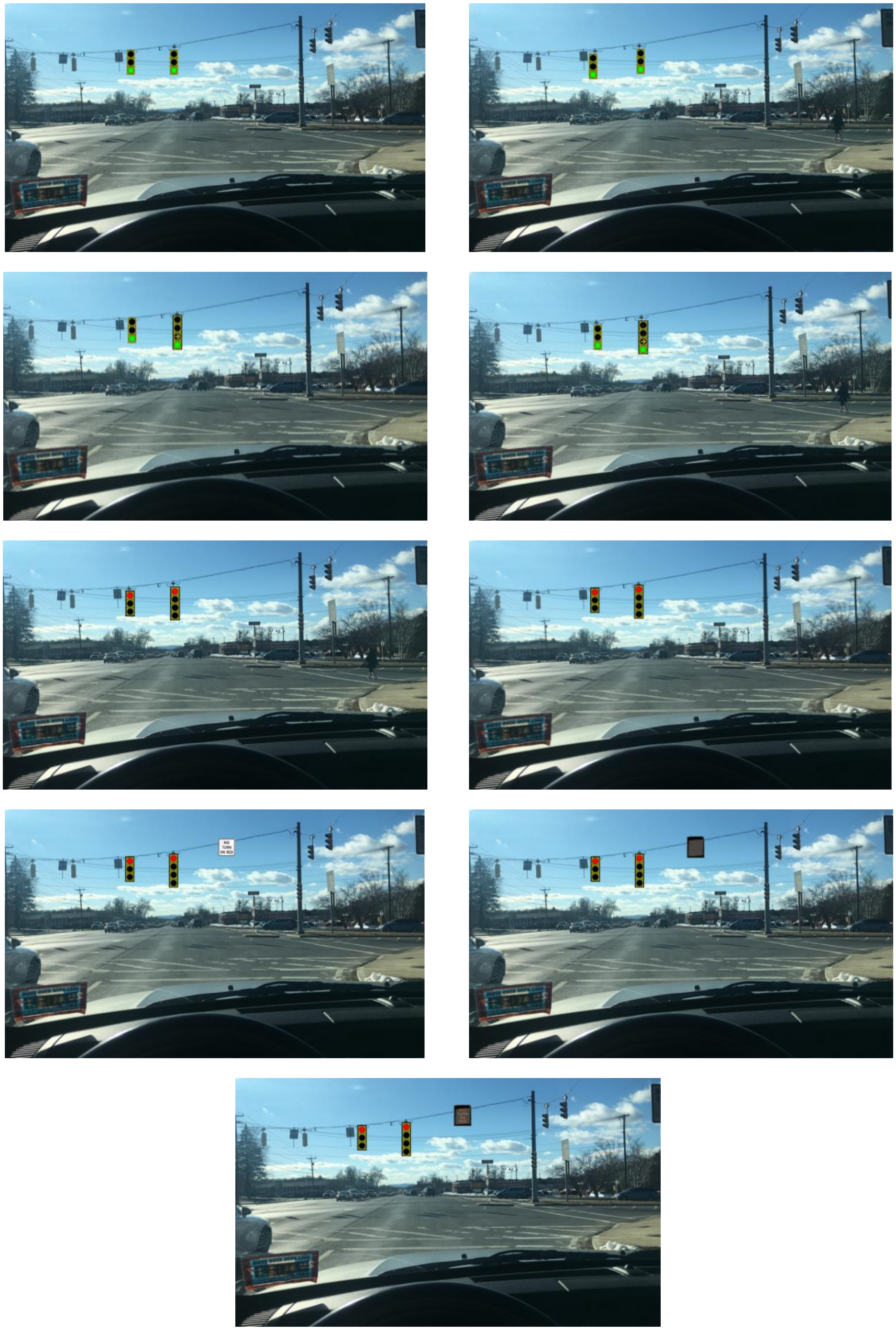

Figure 3.1 The nine images used to depict the survey scenarios

In response to the scenario questions, respondents were given the ability to select as many options as they deemed fit. These options remained consistent for each scenario, and the statements with responses are presented in Table 3.2.

Table 3.2 Survey response options

"As a driver turning right, check all those that apply to the scenario shown in the picture above."	
Pedestrians likely present*	Proceed through intersection if clear
Right turn permitted	Yield before entering intersection
Driver has the right of way	Stop and wait for an alternate signal
Pedestrian has the right of way	None of the above
Must complete stop at stop line before proceeding	

*This response is not listed for scenarios when the pedestrian crossing is present.

In the event that the respondent selected the "Pedestrian likely present" option, the Logit function built into SurveyMonkey would enable a follow-up question before showing the next scenario. The follow-up question asked the respondent to predict where the pedestrian would be crossing. This follow-up question displayed an image of the designated intersection for each signal phase denoting the locations of the crosswalks marked with an "A" or "B," as seen in Figure 3.2. The respondents were asked "You selected 'Pedestrians Likely Present'; based on the picture below where would the pedestrians likely be?" and provided the choices of "Crosswalk A," "Crosswalk B," or "Both A and B."

Figure 3.2 Crosswalk image used in the survey to determine the pedestrian location

3.3 Statistical Testing

The Chi^2 statistical test was performed on various results of the static evaluation to determine the statistical significance in comparisons of particular variables. The initial statistical analysis performed was between the number of male and female responses due to the large difference in value. The survey scenario variable responses to be assessed included circular green vs. FYA and circular green with pedestrian vs. FYA with pedestrians.

Using Excel, p-values were calculated for each response option in terms of their respective signal scenarios. In order to determine the p-value, the expected response values for each signal scenario were calculated from the observed responses. This was done by multiplying the sum of total responses for the given response option to the sum of the total responses for the given signal scenario to then be divided by the sum of all responses for the scenarios in comparison. The expected value is used to determine the chi variable, which is calculated by squaring the difference of the observed-expected response value and dividing that by the expected response value. The sum of the chi variables for the scenarios in the comparison and a *df* value of 1 was input into the equation *=CHISQ.DIST.RT(sum, df)* to produce the statistical p-value. This process was performed on each response option for all scenario comparisons in question. All p-values less than 0.05 were considered statistically significant.

4 Results: Static Survey Evaluation

The results of the static evaluation were found to be consistent with the objective of this research. Percentages of the responses gathered have been broken down in the section below. In the spring of 2017, this static survey collected 200 anonymous responses from subjects in the Northeast region of the United States.

4.1 Flashing Yellow Arrow Analysis

As previously mentioned, the respondents' age, gender, and driving experience were collected at the beginning of the survey. In total, 63% of the respondents were female, while the remaining 37% were male. Due to the large difference in male to female responses, a Chi^2 statistical significance test was performed on each participant's responses. This test resulted in a p-value that was greater than 0.5, and therefore gender did not play a significant part in the responses made during the survey. As a result, all responses were analyzed as a general population. The driving experience of the respondents was as follows: 9.5% had less than five years, 35.5% had five to nine years, and 55% had over ten years. There was no statistical difference in the remainder of the demographic information.

When comparing the circular green indication to the right FYA, the responses decreased for 'Right turn permitted' from 93% to 89% and for 'Driver has the right of way' from 43% to 32%. There was minimal variation in the number of responses from the non-pedestrian circular green to the non-pedestrian right FYA for response 'Must complete stop at stop line before proceeding' (11.9% to 11.5%) or 'Stop and wait for alternate signal' (1.5% to 3.8%). For both non-pedestrian and pedestrian scenarios, the response rates when comparing circular green to right FYA increased from 24% to 57% and 35% to 69%, respectively. The full breakdown of results can be seen in Table 4.1.

Table 4.1: Compiled results for the nine survey scenarios in question

Answer Option / Indication	Circular Green	Circular Green + Pedestrian	Right Flashing Yellow Arrow	Right Flashing Yellow Arrow + Pedestrian	Circular Red
Pedestrians likely present	53.1%	--	50.8%	--	44.7%
Right turn permitted	93.3%	88.9%	88.5%	89.1%	68.2%
Driver has the right of way	43.8%	14.2%	32.8%	15.5%	4.7%
Pedestrian has the right of way	48.5%	86.3%	47.0%	84.5%	54.7%
Must complete stop at stop line before proceeding	11.9%	13.7%	11.5%	11.5%	84.1%
Proceed through intersection if clear	82.5%	72.6%	66.7%	69.0%	33.5%
Yield before entering intersection	24.7%	35.8%	57.4%	69.0%	22.4%
Stop and wait for an alternate signal	1.5%	1.1%	3.8%	4.0%	30.6%
None of the above	0.0%	1.1%	0.5%	0.6%	0.6%
Crosswalk A	5.8%	--	1.1%	--	48.0%
Crosswalk B	57.3%	--	60.2%	--	5.3%
Both A and B	36.9%	--	38.7%	--	46.7%

Table 4.1: Compiled results for the nine survey scenarios in question (Continued)

Answer Option / Indication	Circular Red + Pedestrian	Original No Turn On Red Sign	Dynamic No Turn On Red Off	Dynamic No Turn On Red On
Pedestrians likely present	--	42.1%	42.2%	43.0%
Right turn permitted	71.4%	5.5%	80.7%	7.0%
Driver has the right of way	3.6%	1.2%	7.5%	4.4%
Pedestrian has the right of way	88.7%	45.7%	52.8%	50.6%
Must complete stop at stop line before proceeding	85.7%	22.6%	84.5%	24.1%
Proceed through intersection if clear	38.1%	0.6%	43.5%	3.8%
Yield before entering intersection	30.4%	3.0%	29.2%	3.8%
Stop and wait for an alternate signal	29.2%	90.9%	22.4%	89.2%
None of the above	0.0%	4.9%	0.6%	4.4%
Crosswalk A	--	31.6%	42.0%	29.7%
Crosswalk B	--	5.3%	8.7%	6.8%
Both A and B	--	63.2%	49.3%	63.5%

Based on the Chi^2 statistical test performed on all response variables as seen in Table 4.2, there was only a significant difference found in the 'Yield before entering intersection' response from the circular green to the right FYA for both the non-pedestrian and pedestrian scenarios. Based on the survey results, there is a direct correlation in the results that support the variation in signal display while performing a right turn, as presented in Figure 4.1. Similarly, for the permissive phase and right FYA scenarios, 53% to 51% of respondents, respectively, acknowledged the likelihood of a pedestrian presence. During the permissive phase, the majority of respondents (57.3%) predicted that pedestrians would be crossing crosswalk B at the circular green signal. This percentage increased to 60.2% when the FYA was introduced as displayed in Figure 4.2. A large percentage (36.9% for circular green and 38.7% for FYA) observed that there could be pedestrians present to use both crosswalks A and B.

Table 4.2 Breakdown of Chi2 statistical testing on traffic signal survey responses

Responses	Circular Green	FYA	p-value	Circular Green +pedestrian	FYA+ pedestrian	p-value
Pedestrians likely present	103	93	0.793	--	--	--
Right turn permitted	181	162	0.668	169	155	0.428
Driver has the right of way	85	60	0.091	27	27	0.995
Pedestrian has the right of way	94	86	0.870	164	147	0.328
Must complete stop at stop line before proceeding	23	21	0.930	26	20	0.373
Proceed through intersection if clear	160	122	0.085	138	120	0.257
Yield before entering intersection	48	105	**<0.001***	68	120	**<0.001***
Stop and wait for an alternate signal	3	7	0.171	2	7	0.096
None of the above	0	1	0.302	2	1	0.562
Crosswalk A	6	1	0.071	--	--	--
Crosswalk B	59	56	0.947	--	--	--
Both A and B	38	36	0.964	--	--	--

* P-values considered statistically significant

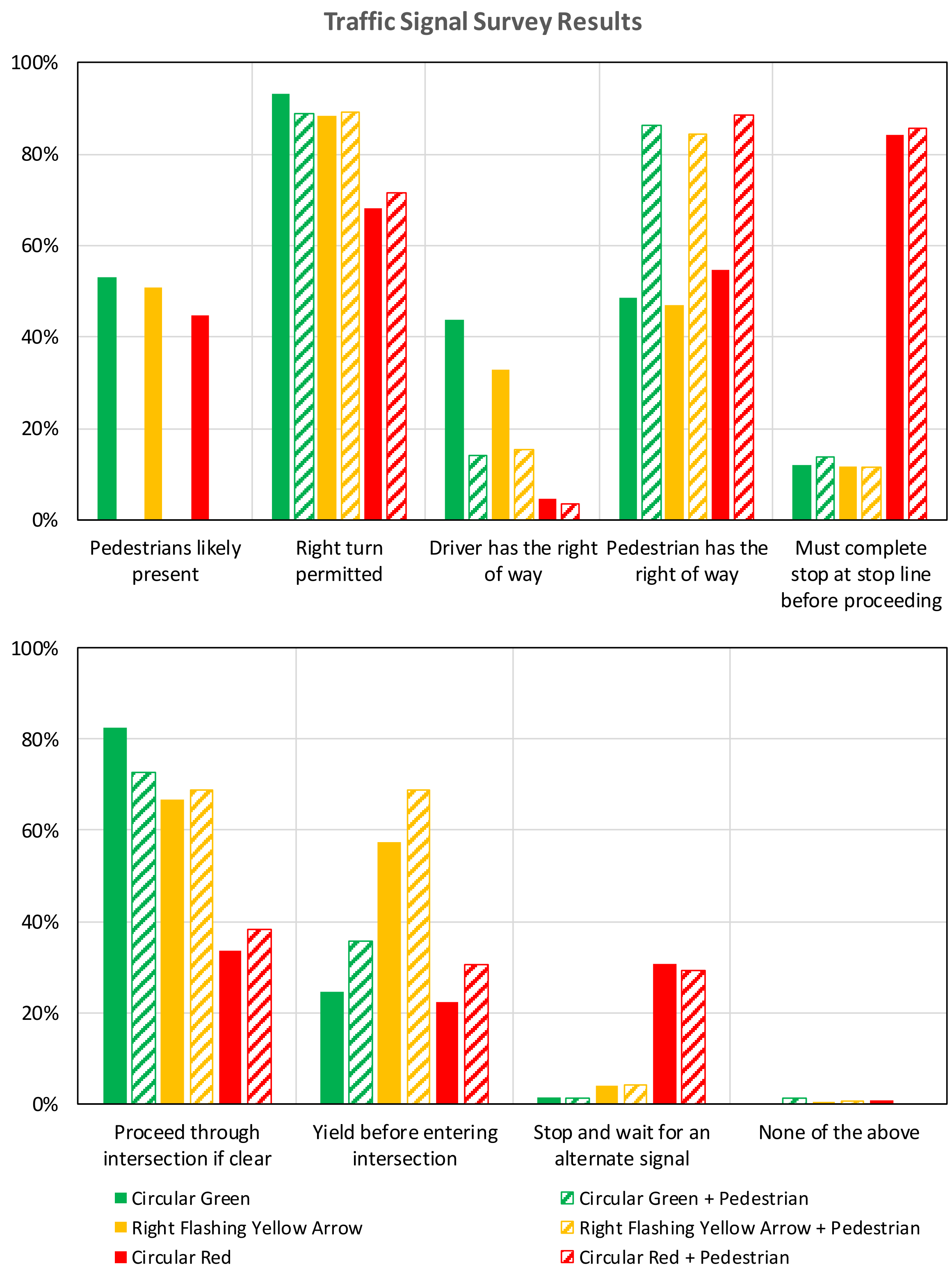

Figure 4.1 Survey responses for traffic signal scenarios

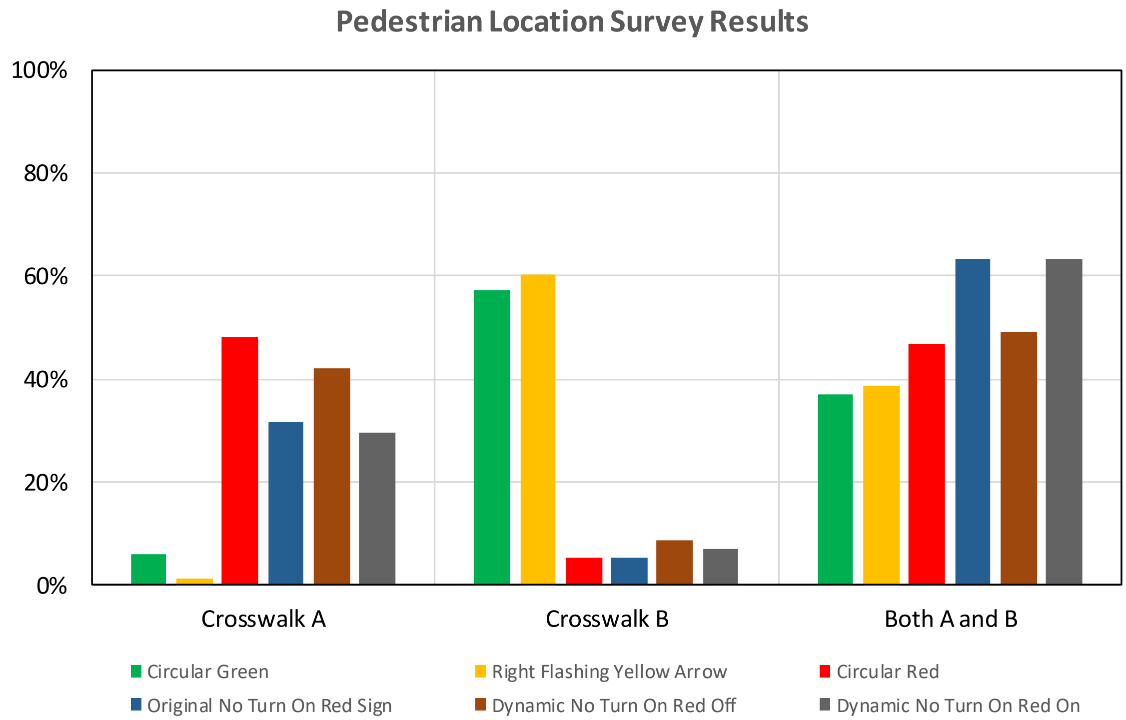

Figure 4.2 Survey responses for pedestrian location scenarios

4.2 Right Turn on Red Analysis

During the red phase scenarios, the existing condition red circular indication responses were compared to the deactivated dynamic no turn on red device. Further, the current R10-11 (No Turn on Red) sign responses were compared to the new activated dynamic no turn on red device. These results are broken down for each condition based on the selected response as shown in Figure 4.3 and listed in Table 4.1. For each comparison, the responses for the new device showed similar trends to the existing conditions. For all four scenarios, there was a 43% average response rate that pedestrians would likely be present, with a heavy understanding that pedestrians would be crossing at crosswalk A as seen in Figure 4.2 and a distinct recognition that both crosswalks could be utilized, i.e., during an all-red phase.

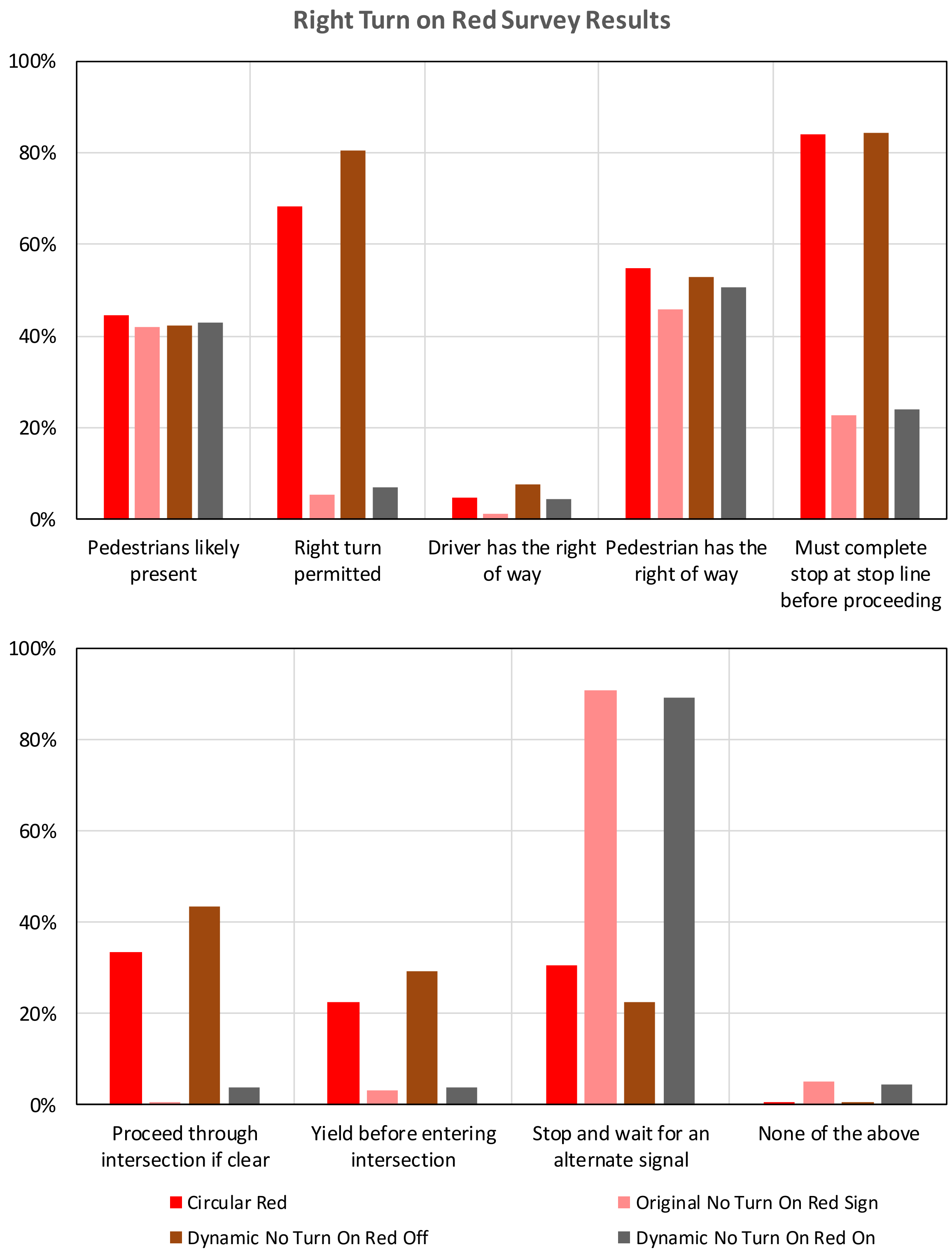

Figure 4.3 Survey responses for right turn on red scenarios

Initially, respondents were asked if a right turn was permitted during each red phase condition. The circular red and the R10-11 sign yielded a response of 68.2% and 5.5%, respectively, that a right turn is permitted. This created a basis of understanding of turn regulations for comparison with the new device. The deactivated responses showed that 80.7% respondents identified that RTOR is permitted, and while the sign was activated, only 7% responded that it is permitted. The response 'Must complete stop at stop line before proceeding' revealed that there was a 0.4% difference in responses between the circular red signal (84.1%) and the deactivated dynamic no turn on red sign (84.5%) scenarios. The current R10-11 and the new activated dynamic no turn on red sign yielded a 90.9% and 89.2% response rate, respectively, for the 'Stop and wait for an alternate signal' option to conclude that no right-turn movement can be made in these two instances. Performing the statistical Chi^2 test on all existing and proposed conditions for the red phase showed no statistical difference between the compared scenarios, as seen in Table 4.3.

Table 4.3 Breakdown of Chi^2 statistical testing on right turn on red survey responses

Responses	Circular Red	Dynamic OFF	p-value	R10-11	Dynamic ON	p-value
Pedestrians likely present	76	68	0.535	69	68	0.857
Right turn permitted	116	130	0.341	9	11	0.68
Driver has the right of way	8	12	0.362	2	7	0.100
Pedestrian has the right of way	93	85	0.583	75	80	0.763
Must complete stop at stop line before proceeding	143	136	0.722	37	38	0.964
Proceed through intersection if clear	57	70	0.232	1	6	0.062
Yield before entering intersection	38	47	0.312	5	6	0.783
Stop and wait for an alternate signal	52	36	0.095	149	141	0.544
None of the above	1	1	0.996	8	7	0.772
Crosswalk A	36	29	0.402	24	22	0.727
Crosswalk B	4	6	0.519	4	5	0.757
Both A and B	35	34	0.929	48	47	0.856

5 Research Methods: Data Collection for Field-Based Evaluation

In the city of Madison, Wisconsin, the use of FYA for right-turn applications has been growing on intersections with significant pedestrian traffic. The typical application of right-turn FYA in Madison presents drivers with an FYA that overlaps the pedestrian WALK indication, thus reminding drivers that they need to yield to pedestrians on the crosswalk. For instances in which a signal head with an FYA is installed higher than the pedestrian signal or even installed above a lane, one of the advantages of a right-turn FYA installation is that the indication can be seen further upstream by drivers than the pedestrian WALK indication. Figure 5.1 shows examples of intersections in the City of Madison that use a right-turn FYA indication.

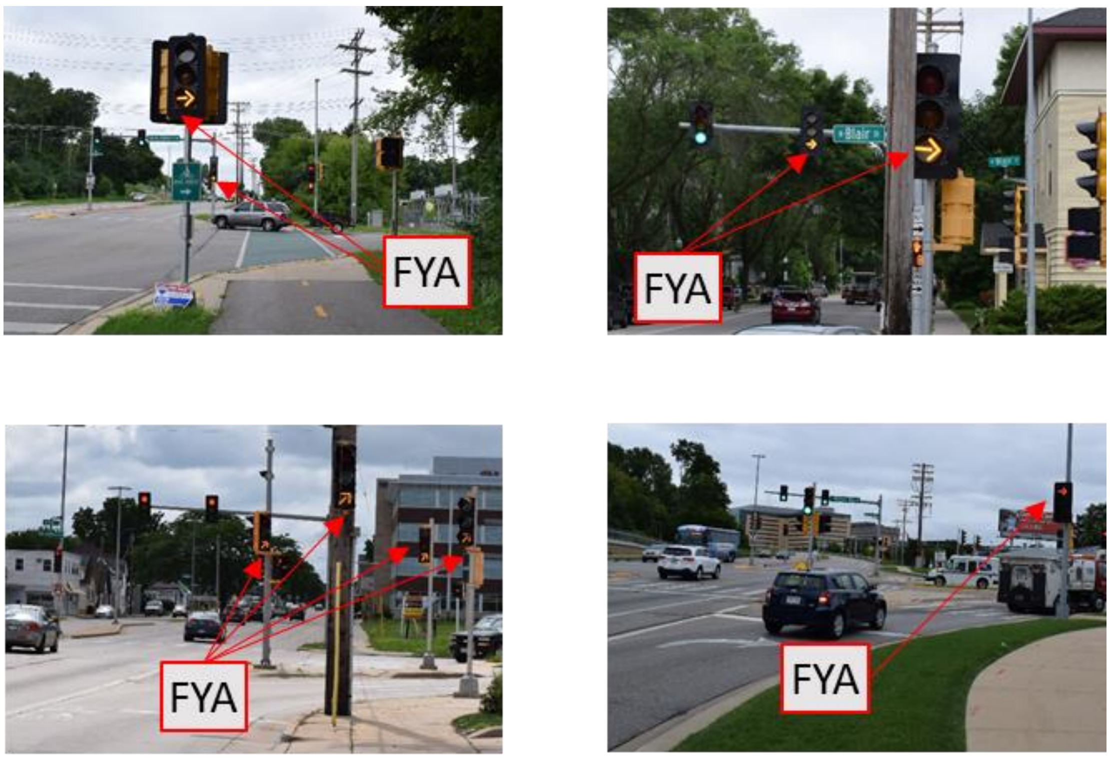

Figure 5.1 Intersections in the City of Madison with FYA

Using video recordings, the interaction between vehicles and pedestrians at intersections in the City of Madison were documented. Video recordings were used to document the time at which pedestrians and vehicles crossed the points t_1, t_2, t_{1P}, and t_{2P} shown in Figure 5.2. The time was documented by analyzing video recordings on a frame-by-frame basis using an MPV video player. Vehicle-pedestrian interactions documented were those during which a single pedestrian traveled through the crosswalk while a leading right-turning vehicle approached the conflict point between the vehicle and the pedestrian (t_2). A leading right-turning vehicle refers to a vehicle that entered the intersection (arrived at t_1) while the right-turn signal displayed either a circular green or an FYA.

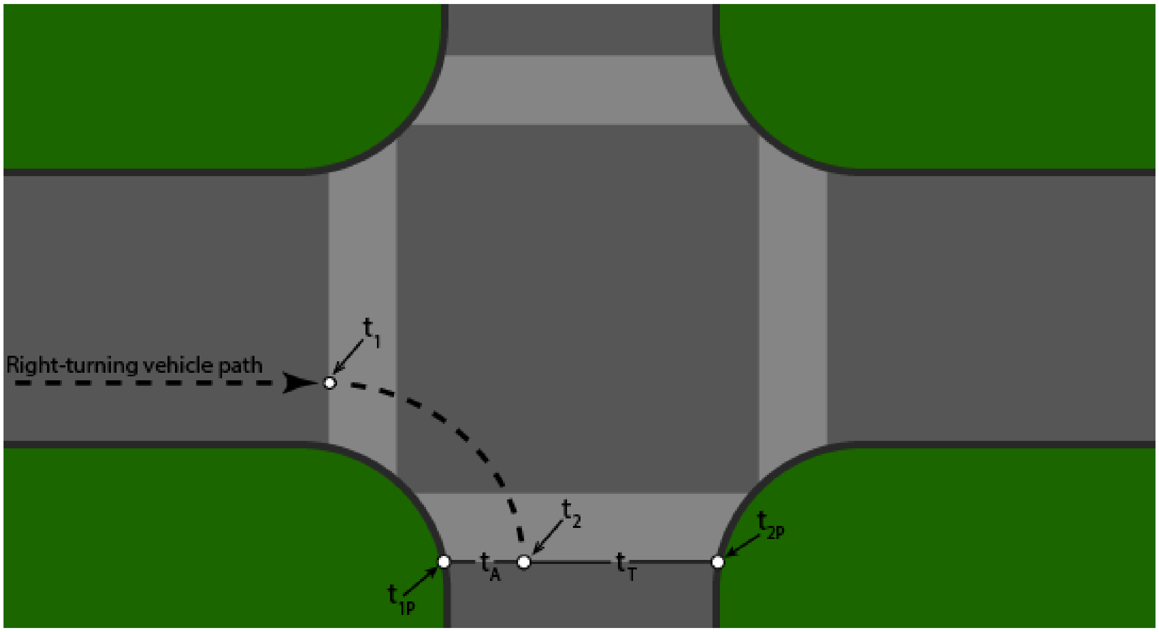

Figure 5.2 Points of interest for field data collection

In Figure 5.2, the t_1 point represents the stop bar located immediately upstream of a crosswalk. The point t_2 represents the downstream edge of the crosswalk used by conflicting pedestrians. In addition to the timestamps documented, the direction of the pedestrian and the type of vehicle (passenger car or no passenger car) were also documented. Bicyclists who used the crosswalk were not considered pedestrians for analysis purposes and therefore were not included in the dataset.

5.1 Vehicle and Pedestrian Behavior Measurements

Data were collected at three intersections without an FYA indication for the right-turn movement and at one intersection with an FYA indication for the right-turn movement. Photographs of the FYA site are shown in Figure 5.3. A total of 10 hours of non-FYA video and 4.5 hours of FYA video were processed. In addition to assembling a dataset of vehicle-pedestrian interactions, during the video processing stage, a dataset of right-turning vehicle behavior on each site when there were no pedestrians present was also assembled. The aforementioned dataset was used to document the average behavior of drivers at each site when there were no conflicting pedestrians present. As a result, the calculation of the change in vehicle travel time measurement (discussed later) was made possible for interactions between vehicles and pedestrians.

Using observations made from the video, a number of derived measurements were calculated and are discussed in the following sections. The aim of these derived measurements is to explain the behavior of drivers who encounter a conflicting (or possibly conflicting) pedestrian when making a right turn. Each measurement is calculated using the timestamps extracted from the frame-by-frame analysis of the video. The measurements shown in the next sections are key to the model-based analysis presented in this report.

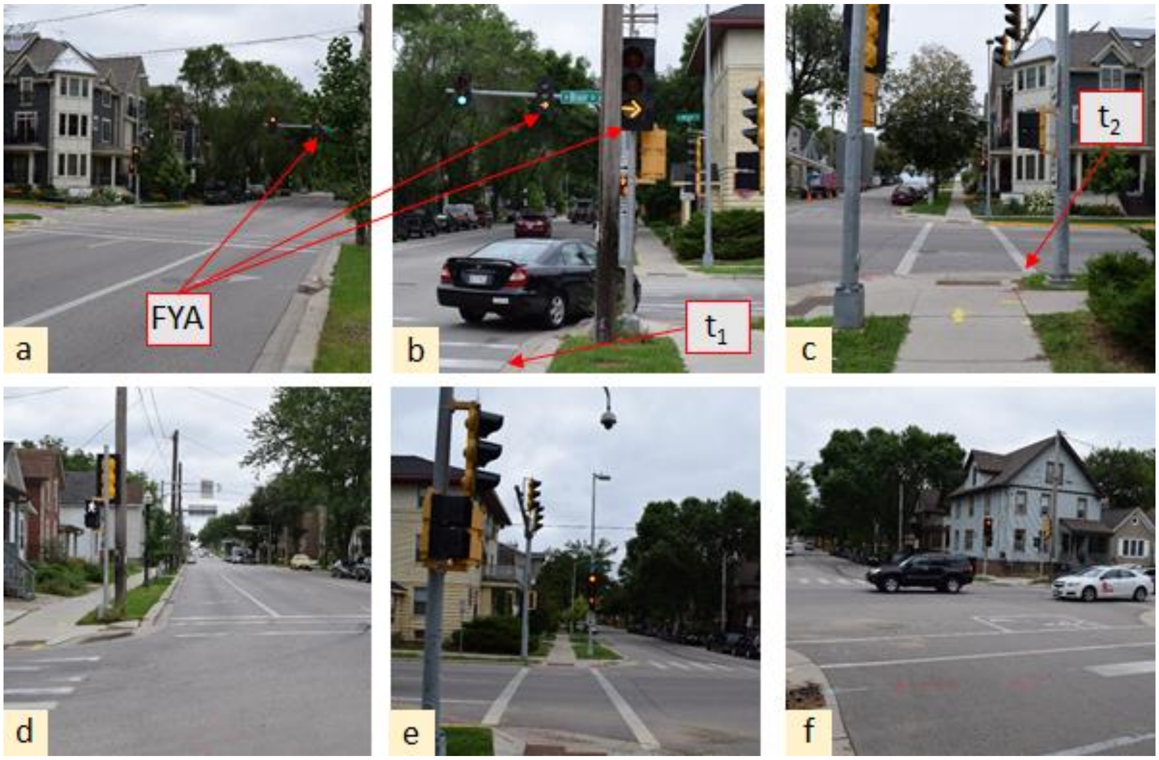

Figure 5.3: Right-Turn FYA Site (East Johnson and North Blair Street)

5.1.1 Pedestrian Travel Time (P_{TT})

The value of P_{TT} for each vehicle-pedestrian interaction was calculated by measuring the time it took pedestrians in the dataset to travel from point t_{1P} to t_{2P} (Direction A) or from point t_{2P} to t_{1P} (Direction T). A key assumption made when using the P_{TT} value is that pedestrians maintain the same speed when navigating the crosswalk.

5.1.2 Vehicle Travel Time (V_{TT})

The value of V_{TT} for each vehicle-pedestrian interaction was calculated by measuring the time it took a right-turning vehicle to travel between points t_1 and t_2. V_{TT} is therefore directly correlated to speed. As in the case of P_{TT}, computations and the use of P_{TT} assume that vehicles maintained the same speed while navigating between t_1 and t_2. This assumption is made solely for the purpose of modeling behavior since having a vehicle completely stop to yield to a pedestrian will significantly lower the travel time.

5.1.3 Unobstructed Vehicle Travel Time (UV_{TT})

The average V_{TT} value for instances in which there were no conflicting pedestrians present at the intersection was computed for leading right-turning vehicles and is referred to as UV_{TT}. To account for speed and behavior changes during different time periods, an average UV_{TT} value was computed for each data collection period.

5.1.4 Change in Vehicle Travel Time (V_{TTC})

For each vehicle-pedestrian interaction, the difference between the individual V_{TT} value and the data collection period UV_{TT} value was calculated to determine the change in vehicle travel time (V_{TTC}) as a result of the presence of a pedestrian. In order to compare V_{TTC} values across multiple sites, the V_{TTC} value is expressed as a percentage change. A positive V_{TCC} value is indicative of an increase in speed as a result of a pedestrian presence, while a low negative value is indicative of the opposite. Therefore, the "more negative" a V_{TTC} value is the safer than the vehicle-pedestrian interaction can be considered.

5.1.5 Position of Pedestrian at Vehicle Entrance (VP_{t1})

To compute the VP_{t1} value, the difference between t_1 and t_{1P} (Direction A) or the difference between t_1 and t_{2P} (Direction T) were calculated and divided by the absolute difference of t_{1P} and t_{2P}. As a result, VP_{t1} represents how far (measured as a percentage) a pedestrian was along the crosswalk when a right-turning vehicle arrived at t_1. A negative value of VP_{t1} indicates that the pedestrian entered the crosswalk after the right-turning vehicle arrived at point t_1.

5.1.6 Pedestrian Position from Conflict Point (PP_{t2})

Pedestrians traveling in Direction A have a theoretical conflict point located approximately 33% from the start point of their crossing point (t_{1P}). Similarly, pedestrians traveling in Direction T have a theoretical conflict point (C_P) located approximately 66% from the start of their crossing point (t_{2P}). The C_P locations mentioned are for illustration purposes and are based on the site shown in Figure 5.3. For each location in the dataset, actual C_P locations were measured and used in the calculations. Using the location of the C_P and the VP_{t1} value for each vehicle-pedestrian interaction, the distance of the pedestrians from the C_P (PP_{t2}) was determined by calculating the difference between the location of the C_P and VP_{t1}. As in the case of VP_{t1} and V_{TTC}, in order to facilitate comparison of values across multiple sites, the distance is calculated as a percentage of the crosswalk length.

6 Results: Field-Based Evaluation

Datasets containing vehicle-pedestrian interactions at FYA and non-FYA locations were combined for analysis. Two models were created to explain the *change in vehicle travel time* (V_{TTC}) as a function of the *pedestrian position from conflict point* (PP_{t2}). The first model considers the behavior of drivers prior to pedestrians reaching the conflict point. The second model considers the behavior of drivers across the range of vehicle positions, i.e., prior to pedestrians reaching the conflict point and once pedestrians are past the conflict point.

6.1 Model: Before Pedestrian Reaches Conflict Point

A visual representation of the dataset used to create the model is shown in Figure 6.1. The figure shows the dataset separated into vehicle-pedestrian interactions on an FYA site and those on non-FYA (circular green) sites. Simple regression lines across the data points for each site suggest there is a degree of parallelism between the lines and that the regression line for the FYA dataset is lower than the line for the non-FYA dataset. Exploratory parametric tests based on an analysis of co-variance conducted on the dataset suggest that the lines could be considered parallel; however, prior to making a statistically sound assessment, additional data is needed and should be collected as part of future work.

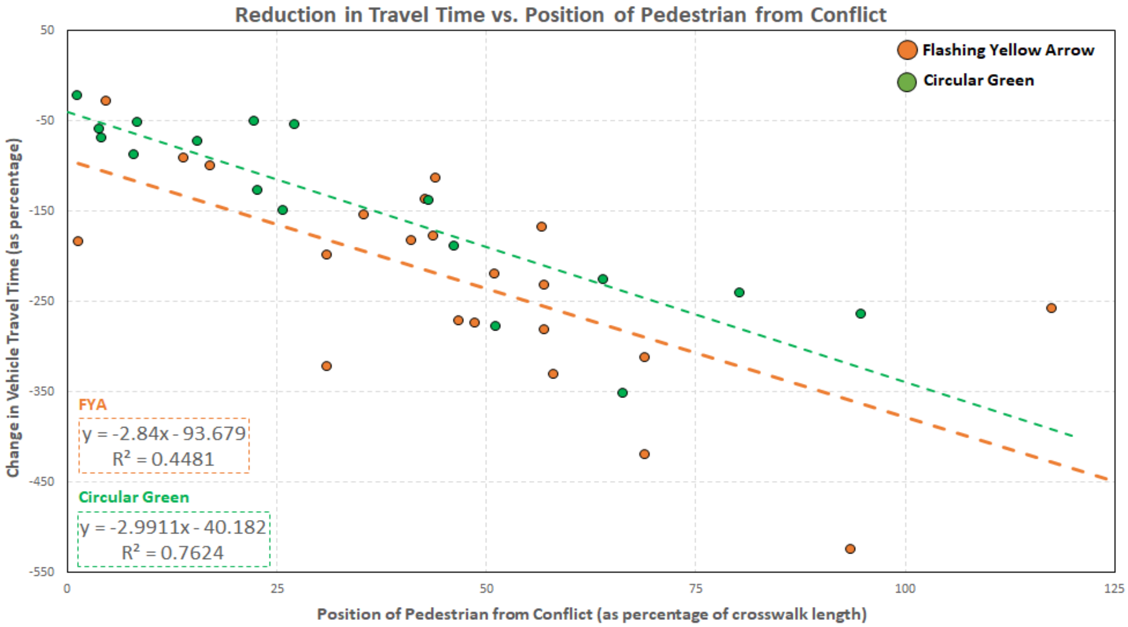

Figure 6.1 Data points for model (before pedestrian reaches conflict point)

Negative PP_{t2} values were excluded from the dataset shown in Figure 6.1. Negative values were excluded since an argument can be made that once a pedestrian is past the conflict point, there is limited to no perceived danger by drivers, thus warranting a separate analysis. PP_{t2} values greater than 100 percent remained in the analysis dataset since these values represent vehicle-pedestrian interaction instances in which a pedestrian was approaching (but had not entered) the crosswalk when the vehicle arrived at t_1. The details for the two regression lines shown in Figure 6.1 are presented in Table 6.1, Table 6.2, and Table 6.3.

Table 6.1 FYA model details

Coefficients	Estimate	Standard Error	t Value	p Value
Intercept	-93.68	37.85	-2.48	0.02
PP_{t2}	-2.84	0.71	-4.03	6.56×10^{-4}
N = 22 | Multiple R-squared: 0.4481, Adjusted R-squared: 0.4206				
F-statistic: 16.24 on 1 and 20 DF, p-value: 0.0006557				

Table 6.2 Non-FYA model details

Coefficients	Estimate	Standard Error	t Value	p Value
Intercept	-40.18	19.11	-2.10	0.05
PP_{t2}	-2.99	0.43	-6.94	4.74×10^{-6}
N = 17 | Multiple R-squared: 0.7624, Adjusted R-squared: 0.7466				
F-statistic: 48.14 on 1 and 15 DF, p-value: 4.744e-06				

Table 6.3 Multiple linear regression model details

Coefficients	Estimate	Standard Error	t Value	p Value
Intercept	-42.96	22.89	-1.88	0.069
isFYA	-47.42	23.90	-1.98	0.055
PP_{t2}	-2.91	0.43	-6.80	6.08×10^{-8}
N = 39 | Multiple R-squared: 0.6213, Adjusted R-squared: 0.6002				
F-statistic: 29.53 on 2 and 36 DF, p-value: 2.568e-08				

6.2 Model: Before and after Pedestrian Reaches Conflict Point

A visual representation of the dataset used to create the model is shown in Figure 6.2. As in the case of Figure 6.1, Figure 6.2 shows the dataset separated into vehicle-pedestrian interactions on an FYA site and those on non-FYA (circular green) sites. Simple regression lines across the data points for each site suggest there is a difference in the slopes. However, when the dataset is analyzed using a multiple linear regression approach that considers the presence of an FYA as a factor, the factor does not appear to be significant. The model details are shown in Table 6.4.

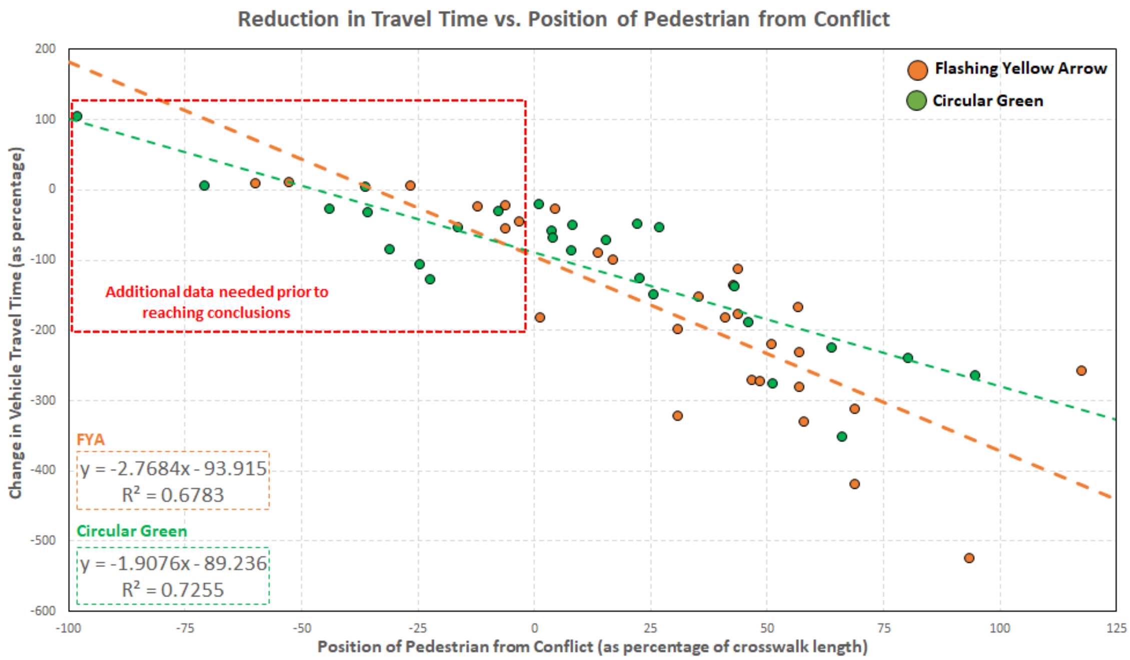

Figure 6.2 Data points for model (expanded pedestrian position)

The model visualization in Figure 6.2, along with the model details described in Table 4.2, highlight the need for additional data to better understand the behavior of drivers once pedestrians are past the conflict point. While, in theory, once a pedestrian is past the conflict point the perceived danger is eliminated (or significantly reduced), an argument can be made that driver behavior could still be impacted by the presence of pedestrians and reflected in the V_{TTC} value. Future work should focus on collecting additional data to increment the number of points with negative PP_{T2} values and understand the nature of vehicle-pedestrian interactions in the range of values.

Table 6.4 Multiple linear regression model details

Coefficients	Estimate	Standard Error	t Value	p Value
Intercept	-86.32	13.44	-6.42	3.81×10^{-8}
isFYA	-21.55	19.19	-1.12	0.266
PP_{t2}	-2.30	0.22	-10.40	2.07×10^{-14}
N = 39 | Multiple R-squared: 0.7002, Adjusted R-squared: 0.6889				
F-statistic: 61.9 on 2 and 53 DF, p-value: 1.363e-14				

7 Discussion

Two experimental approaches were presented in this report to understand the effects of FYA indications on right turns. The first experimental approach relies on static surveys that help establish the foundation for a future simulation and expanded field study, while the second one is a field-based evaluation that demonstrates the feasibility of obtaining naturalistic-style data for a future study. The sections ahead discuss some of the results, lessons learned, and future work that can expand the effort outlined in this report.

7.1 Survey-Based Evaluation

Survey results showed how respondents supported the basis of the research hypothesis. This research was intended to evaluate drivers' comprehension and awareness while making a right turn at the signalized intersection signal in question. To determine the driver's understanding of permissive right turns, the existing circular green indication scenario was compared to the proposed signal condition containing an FYA for right-turn applications. The existing condition set a baseline for driver comprehension as they thought through the action of making a right turn in two scenarios, with and without a pedestrian crossing. The options provided throughout the static evaluation remained constant, and therefore the results of each selection between the existing and proposed conditions were compared.

The decrease in responses from the circular green to the right FYA scenarios for options including 'Right turn on red' and 'Driver has the right of way' provides the anticipated intention to relay an additional sense of warning in the signal meaning. This warning leads to higher caution or more hesitation while approaching a signalized intersection with a right FYA. A small percent change for the response options "Must complete stop at stop line before proceeding" and "Stop and wait for alternate signal" proves there was little to no confusion with the implementation of the new signal. For all four of these options, the lack of statistical difference as result of the Chi^2 test indicates the similar understanding of the new FYA signal.

"Yield before entering intersection" was the response option that greatly supported the research objective. When comparing the circular green at 24.7% to the right FYA at 57.4%, the response rate basically doubled. The new display incorporating flashing and the warning yellow color increases driver attention and yielding behavior. Performing the Chi^2 test determined the statistical significance occurs in terms of the yield response as a direct factor of the FYA signal.

The majority of survey respondents acknowledged the possibility of pedestrians crossing at signalized intersections. When further asked at which location the pedestrian would be crossing, drivers determined most pedestrians to be found in the crosswalk parallel to the through lane. Respondents did consider pedestrians may be using the crosswalk without the walk signal due to the uncertainty of pedestrian behavior. This understanding of pedestrian location provides an indication of driver vigilance to other roadway users, showing increasing attention towards pedestrians rather than solely vehicles.

The existing conditions during the red phase consisted of a circular red ball signal and a circular red ball signal with the R10-11 "No Turn on Red" sign. The majority of respondents acknowledged that a right turn is permitted when just a circular red is displayed, while only five percent of responders believed one can turn with an R10-11 sign present. Comparing the existing to proposed conditions, survey results showed strong similarities. When the dynamic no turn on red sign was deactivated, most the respondents identified that a right turn was permitted, emulating the current red ball signal condition. In the scenario when the dynamic no turn on red was activated, only seven percent of respondents said that an RTOR is permitted, which is not far off from the five percent originally documented when the R10-11 sign is displayed. Statistical testing was performed on all response options, and in terms of the proposed and existing conditions, there are no statistical differences in responses. The less than one percent difference in response rates between the circular red signal and the deactivated dynamic no turn on red for the "Must complete stop at stop line before proceeding" option validates driver comprehension across both scenarios to stop before entering the intersection. It can be concluded that there are significant similarities in the understanding of the signs' intended message.

7.1.1 Limitations

This study administered a static evaluation to respondents to perform at their own time and pace. While testing the understanding of the signal meaning and how drivers say they would respond, real-time decision-making was not considered. The limited real-time component is believed to minimize initial instinct and increase contemplation of response selection.

7.1.2 Future Work

Future studies will implement the use of driving simulation to further define how the FYA for right-turn applications and dynamic no turn on red increase intersection safety through an analysis of driver behavior. Implementing this method would safely test the understanding determined in the survey in the form of action and physical behavior.

7.2 Field-Based Evaluation

Vehicle-pedestrian interactions were documented on sites with and without an FYA indication on the right turn. Documentation of the interactions was achieved by analyzing video recordings from the sites using a frame-by-frame analysis approach. When right-turning vehicles entered the intersection, the percentage of the crossing completed by the pedestrian within the crosswalk was documented. Additionally, the time at which the vehicle finished the right turn as well as the time that pedestrians spent in the crosswalk were documented. Documentation of the interactions was limited to instances of a single pedestrian entering the crosswalk and to leading right-turning vehicles. In addition to the vehicle-pedestrian interactions, the average time that vehicles spend making a right turn was documented for instances when no pedestrians were present at the crosswalk in order to establish a baseline behavior on each site.

Using the baseline vehicle behavior, the deviation from expected behavior was computed for each of the vehicle-pedestrian interactions documented. Models of deviation values as a function of the percentage of the pedestrian crossing completed were created. Since the models are based on a limited dataset (1 FYA site and 3 non-FYA sites), strong conclusions cannot be reached from the trends observed. However, the data shows patterns that are worth highlighting. First, modeling driver behavior as a function of the pedestrian position within the crosswalk appears feasible as shown by the significance of the model coefficients. Second, individual models can be generated for vehicle-pedestrian interaction data associated with FYA and non-FYA right turns. Future work can expand the exploratory dataset presented in this report and rely on the expanded dataset to confirm or reject preliminary trends that suggest that drivers presented with an FYA react differently than drivers facing a movement not controlled by an FYA.

7.2.1 Future work

The field-based data collection efforts presented are focused on computing measurements using timestamps values at known points of the intersections. While useful, these measurements are still limited in scope. No detailed vehicle trajectory information is available, thus limiting the type of statistical modeling possible. Detailed vehicle trajectories such as the one shown in Figure 7.1 provide the ability to conduct microscopic-simulation-style evaluations but with actual field data. These types of trajectories could be obtained using data collection devices designed to tap into the underlying data of existing radar-based vehicle detection systems.

Additionally, another key component of future work involves the collection of vehicle-pedestrian interaction data at other sites. The selection of additional sites should focus on identifying locations that allow as much isolation as possible of the effects that a right-turn FYA has on driver behavior. In addition to collecting vehicle-pedestrian interaction data using the approach outlined in this report, two other approaches for data collection should be considered. These two approaches are outlined ahead.

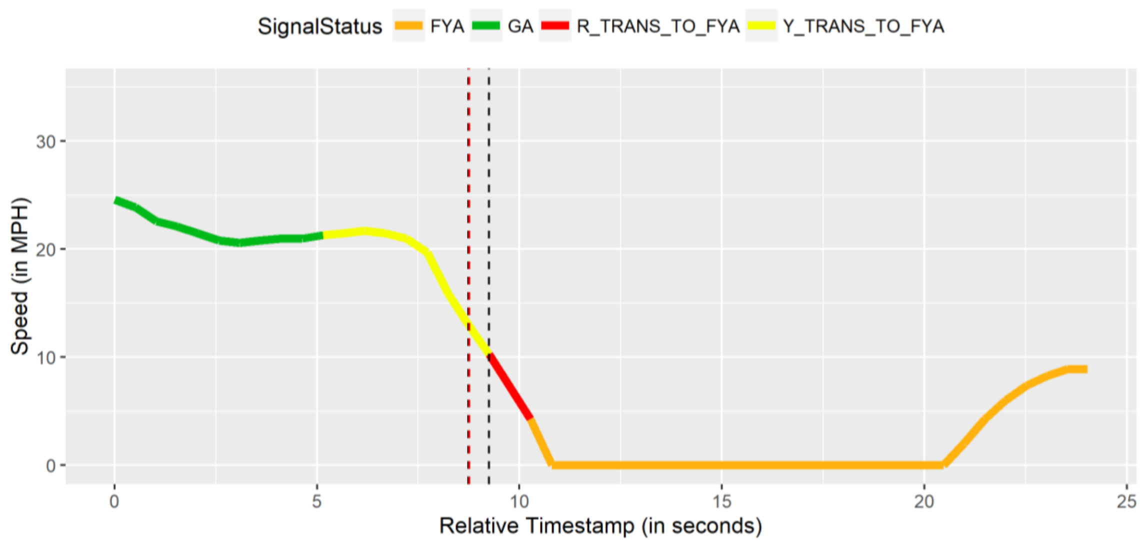

Figure 7.1 Combined vehicle trajectory data and signal status

As Figure 7.1 shows, vehicle trajectory data can be combined with signal status information. And while the figure shows the trajectory of a left turn vehicle, the same type of data could be generated for right-turn movements. Therefore, if field-measured vehicle speed and position, signal status, and pedestrian position are combined, a number of microscopic simulation-style evaluations emerge.

8 Conclusions

Flashing yellow arrows on left turns have the distinct advantage of reinforcing the message to drivers that they need to wait for a gap in the opposing traffic stream before crossing. The FYA concept has been recently expanded to right-turn applications. One of the premises for the use of right-turn FYA is that the indication will reinforce the message that drivers need to yield to conflicting pedestrians. And while drivers' understanding of FYA indications on left turns has been studied extensively, the use of FYA for right-turn applications is an area that needs to be better understood through evaluations focused on actual driver behavior. The objective of this research was to evaluate the driver comprehension and behavior while completing a right-turn maneuver at a signalized intersection that displayed an FYA indication on the right turn. The objectives were achieved through a survey-based evaluation of right-turn FYA scenarios and through a field-based evaluation that established an analysis framework for quantifying the interaction of right-turning drivers and pedestrians.

8.1 Survey-Based Evaluation

While aiming to improve the safety of interactions between vehicles and pedestrians, the FYA for right-turn applications and dynamic no turn on red were evaluated to determine whether drivers grasp the message of the devices. The evaluation was conducted using a computer-based static evaluation. The study evaluated the results from 200 respondents based on the existing passive green and red phase conditions, the proposed right FYA, and the dynamic no turn on red sign. Results indicate that drivers have a strong comprehension of the FYA and dynamic no turn on red messages. There was a significant statistical difference in responses in terms of the increase in the response designating the action of yielding as approaching the intersection from the existing condition to the FYA.

The data reveal that the majority of drivers perceive pedestrians to cross parallel to the green signal, while the FYA scenarios increase the assignment of pedestrians to crosswalk B. Considering the signal scenario options, the general concept of the FYA relaying a warning message for vehicles making a right turn has initially been understood and shown effective to increase yielding. When comparing the red circular ball signal and the R10-11 ("No Turn on Red") sign to the dynamic no turn on red both deactivated and activated, the responses show great similarities with no statistical difference. The majority of the responses indicated that drivers recognize the sign display that permits a right turn on red. The statistically enforced consistency between the existing and proposed conditions proves that the message will yield low levels of confusion upon full implementation.

8.2 Field-Based Evaluation

Vehicle-pedestrian interactions were documented on sites with and without an FYA indication on the right turn as well as on a site with an FYA indication on the right turn. Documentation of the interactions was achieved using a frame-by-frame analysis of video recordings from the sites. The average time that a vehicle spends when making a right turn was documented to establish a baseline behavior when no pedestrians are present. The deviation from the expected time spent on the same maneuver when a pedestrian was present was modeled as a function of the pedestrian position within the crosswalk and the use of a right-turn FYA indication. Modeling driver behavior as a function of the pedestrian position within the crosswalk was found to be feasible, as shown by the significance of the model coefficients. Also, it was found that individual models can be generated for vehicle-pedestrian interaction data associated with FYA and non-FYA right turns, which will make understanding the interactions of vehicles and pedestrians through field observations possible. The feasibility of obtaining the type of results presented will make it possible to assess the validity of a future driving simulation study or allow for characterizing the impact that an FYA indication has on the aggressiveness of right-turning drivers when a pedestrian is present. Both will require an expanded dataset, as the test dataset obtained as part of the research is not sufficient to reach strong conclusions regarding the initial trends observed.

8.3 Collaborative Nature and Implications for Future Driving Simulation Research

This report presented the results of a collaborative project that aims to provide a foundation for future research in how drivers understand FYA indications on right turns through the use of a driving simulator. The foundation was established by conducting a survey-based evaluation of FYA applications on right turns as well as a field-based evaluation that demonstrated the feasibility of quantifying the interactions between pedestrians and right-turning drivers on a site with a right-turn FYA indication. The survey-based evaluation was conducted by UMass-Amherst, while the field-based evaluation was conducted by UW-Madison. The research presented provides a foundation for a future driving-simulator evaluation by narrowing the scenarios that should be evaluated and by providing an analysis framework that allows comparing interactions obtained from direct field observations with interactions obtained as part of a driving simulator experiment.

8.4 Acknowledgments

This research was funded in part through a research project awarded by the Safety Research Using Simulation (SAFER-SIM) University Transportation Center (UTC) at the University of Iowa. Funding for the UTC Program is provided by the Office of Assistant Secretary for Research and Innovation (OST-R) of the United States Department of Transportation (USDOT).

References

1. Choi, E. H. (2010). *Crash factors in intersection-related crashes: An on-scene perspective* (Report No. DOT HS 811 366). Washington, DC: U.S. Department of Transportation.
2. National Center for Statistics and Analysis. (2017, February). *Pedestrians: 2015 data* (Traffic Safety Facts. Report No. DOT HS 812 375). Washington, DC: National Highway Traffic Safety Administration.
3. Brehmer, C. L., Kacir, K. C., Noyce, D.A., & Manser, M. P. (2003). *Evaluation of traffic signal displays for protected/permissive left-turn control* (NCHRP Report No. 493). Washington, DC: Transportation Research Board.
4. Simons, D. J., & Chabris, C. F. (1999). Gorillas in our midst: Sustained inattentional blindness for dynamic events. *Perception*, *28*(9), 1059-1074.
5. Summala, H., Pasanen, E., Räsänen, M., & Sievänen, J. (1996). Bicycle accidents and drivers' visual search at left and right turns. *Accident Analysis & Prevention, 28*(2), 147-153.
6. Preusser, D. F., Leaf, W. A., DeBartolo, K. B., & Blomberg, R.D. (1981). The *effect of right-turn-on-red on pedestrian and bicycle accidents* (Report No. HS-806-182). Washington, DC: U.S. Department of Transportation.
7. Wagoner, W. D. (1992). Driver behavior at right-turn-on-red locations. *ITE Journal, 62*(4), 18-20.
8. Federal Highway Administration (2009). *Manual on uniform traffic control devices (MUTCD*), 2009 Edition. Retrieved March 13, 2018, from http://mutcd.fhwa.dot.gov/pdfs/2009/pdf_index.htm
9. Tipples, J. (2002). Eye gaze is not unique: Automatic orienting in response to uninformative arrows. *Psychonomic Bulletin & Review, 9*(2), 314-318.
10. National Committee on Uniform Traffic Laws & Ordinances (1968). *Uniform Vehicle Code: And Model Traffic Ordinance.* Washington, DC.
11. Hubbard, S. M., Bullock, D. M., & Mannering, F. L. (2009). Right turns on green and pedestrian level of service: Statistical assessment. *Journal of Transportation Engineering, 135*(4), 153-159.
12. Federal Highway Administration (n.d.) Static and active NTOR signs. Retrieved March 13, 2018, from https://safety.fhwa.dot.gov/ped_bike/tools_solve/ped_scdproj/sys_impact_rpt/images/fig13s.jpg